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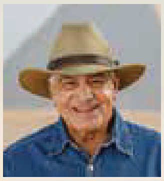

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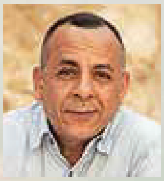

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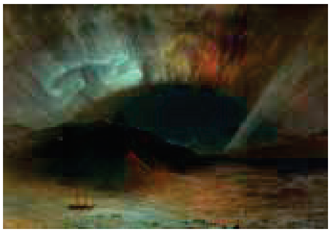

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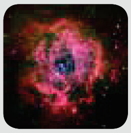

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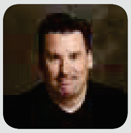

Dave's Universe
The inside scoop from the editor.

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FROM THE EDITOR

Stars and war

Seven weeks after the Battle of Gettysburg, Abraham Lincoln paid a surprise visit to the Old U.S. Naval Observatory in Washington, marking one crossroad of astronomy and the Civil War.
LIBRARY OF CONGRESS

Ever since I became interested in astronomy at age 15, I've also been a big fan of history. Maybe it's reaching out in different ways — into the universal darkness of space, or the infinite reaches of time. Or maybe it was because my dad, a professor of organic chemistry, carted me around to historical sites on vacation when I was a kid. The infection took hold.

After I was given papers and relics from a great-great-grandfather, Darius Wetzel, who fought under generals Grant and Sherman in the greatest American crisis, the Civil War became a focus of my interest in history. So, when I was asked to give a talk about the crossroads of astronomy and the Civil War, I thought I thought it was a great opportunity to produce a story for the magazine too. You'll find it on page 38.

The two subjects, astronomy and history, merged together for me in a transfixing moment on one trip: In Washington in the 1980s, I was able to visit the Old — the original — U.S. Naval Observatory. Long before my time, in the summer of 1863, Abraham Lincoln had visited the observatory on a whim of curiosity, seven weeks after the battle of Gettysburg. Lincoln was a clever and intensely curious person, and the views that a young astronomer gave him that night stuck long and hard in his mind. Lincoln was shown the Moon, the bright star Arcturus, and other sights. The young astronomer who was shocked by the unannounced presidential visit was Asaph Hall, who 14 years later would discover the moons of Mars.

There are other crossroads between the stars and America's transformative conflict: the aurora that shone brightly over Fredericksburg after the battle, taken as an omen by both sides. Two very bright comets in 1861 and 1862. The Moon-shadow mysteries that enabled Stonewall Jackson, the Confederate general, to be accidentally mortally wounded by his own men. And the astronomer who oversaw the famous "Great Locomotive Chase" through Georgia, a raid undertaken by undercover Union scouts.

I hope you'll enjoy reading these stories of long ago that helped to solidify the place we now occupy in history — and that you'll keep some of them in mind as you stare out into the enormous cosmos.

Yours truly,

David J. Eicher
Editor

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Kepler-186f, the first Earth-size planet discovered orbiting a star in the habitable zone, is seen in this 2015 illustration. NASA AMES/SETI INSTITUTE/JPL-CALTECH

We welcome your comments at Astronomy Letters, P.O. Box 1612, Waukesha, WI 53187; or email to ***letters@astronomy.com****. Please include your name, city, state, and country. Letters may be edited for space and clarity.*

Just right for life

Just finished reading "Is Earth the only Goldilocks planet?" (July 2023) for the third time and have an observation. The article does a great job of describing the requirements for life to exist on any other planet in our galaxy, but confines the observations to our galaxy, not the entire universe. If it is true that there are 200 billion galaxies in the universe and an estimated 100 billion stars in each, then the probability of life on a planet in one of those galaxies is 100 percent, in my opinion. —**Bob McRann,** La Mesa, CA

Rare find

I thoroughly enjoyed Klaus Brasch's well-balanced article on the question of complex life in the universe ("Is Earth the only Goldilocks planet?," July 2023). Having read Ward and Brownlee's *Rare Earth*, I found merit with many of their ideas, and issues with a few.

My biggest concern involves how we determine the conditions for life when we don't have a clear idea of the development of life from the beginning. What events would promote or prevent the development of complex life? Consider the Jupiter hypothesis. Although gravitationally the big planet may have offered some protection from impacts with asteroids and comets, there is considerable evidence that mass extinction of species on Earth has occurred several times, so this hypothesis doesn't necessarily explain the existence of life on Earth as exceptional. Life is clearly resilient.

These objections to some of the Rare Earth hypothesis also tie into the resilience of life in the form of extremophiles. Extremes of temperature and pressure provide a broad window for the limits of life on this planet; why not on others? Perhaps my bias against the exceptionalism of life is that it is incredibly tenacious once it gets a foothold. —**John R. Zysk,** La Quinta, CA

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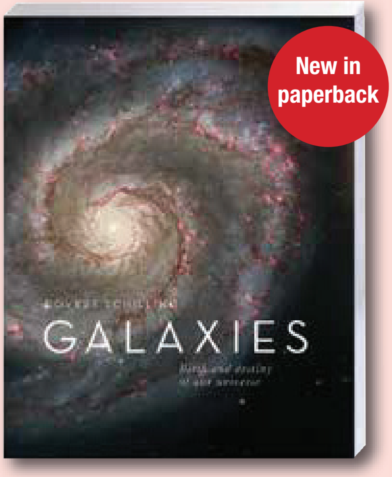

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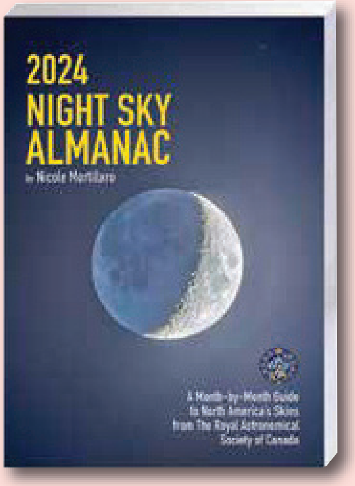
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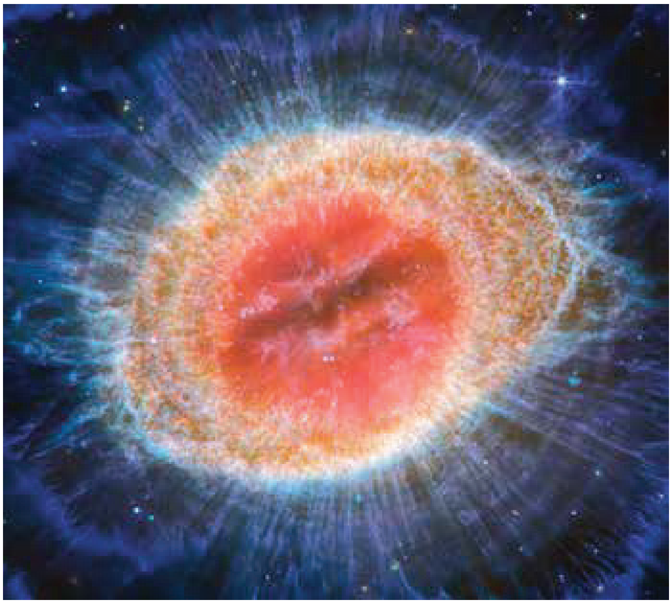
QUANTUM GRAVITY

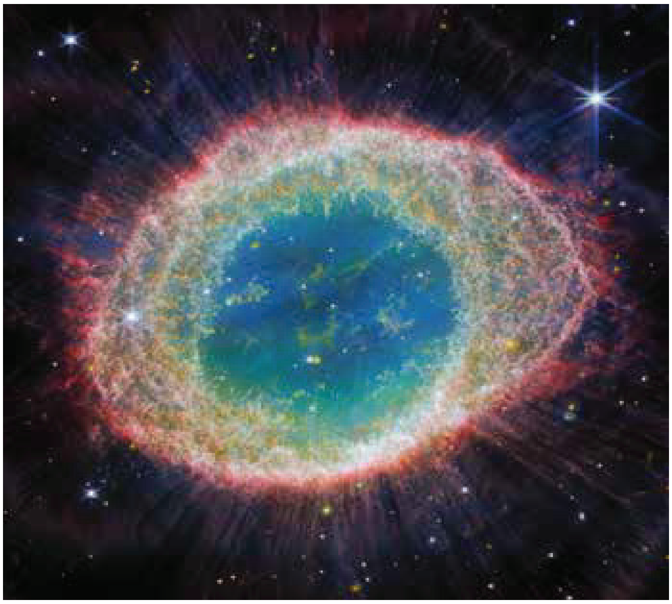
EVERYTHING YOU NEED TO KNOW ABOUT THE UNIVERSE THIS MONTH

SNAPSHOT

JWST SEES THE RING NEBULA IN A NEW LIGHT

New images are helping astronomers understand how Sun-like stars live and die.





The Ring Nebula (M57), 2,200 light-years away in Lyra, is one of the most famous planetary nebulae — the final stages of a dying Sun-like star, shedding its outer layers. But the James Webb Space Telescope (JWST) has produced two striking images that reveal unprecedented detail in its intricate features. At bottom, JWST's Near Infrared Camera captured the complex, filamentary structure of the ring, which is made of about 20,000 individual clumps of dense gas, each with roughly the mass of Earth. At top, the Mid-Infrared Instrument revealed concentric features in the halo that crowns the outer regions of the nebula. The spacing of these features suggests a hidden companion star orbits the central star every 280 years, sculpting the Ring's outflow.

— ELIZABETH GAMILLO

ESA/WEBB, NASA, CSA, M. BARLOW (UNIVERSITY COLLEGE LONDON), N. COX (ACRI-ST), R. WESSON (CARDIFF UNIVERSITY); RIGHT COLUMN FROM TOP: NASA/JPL/SPACE SCIENCE INSTITUTE; J. JOHANSSON; MICHELLE NEGRON, NATIONAL SCIENCE FOUNDATION

»

HOT BYTES

STORMY SATURN

Radio observations of ammonia in Saturn's atmosphere have revealed that the planet's enormous storms — which appear every few decades as a "great white spot" — can cause disruptions in the atmosphere that last for more than 100 years.

ARECIBO'S SHUTDOWN

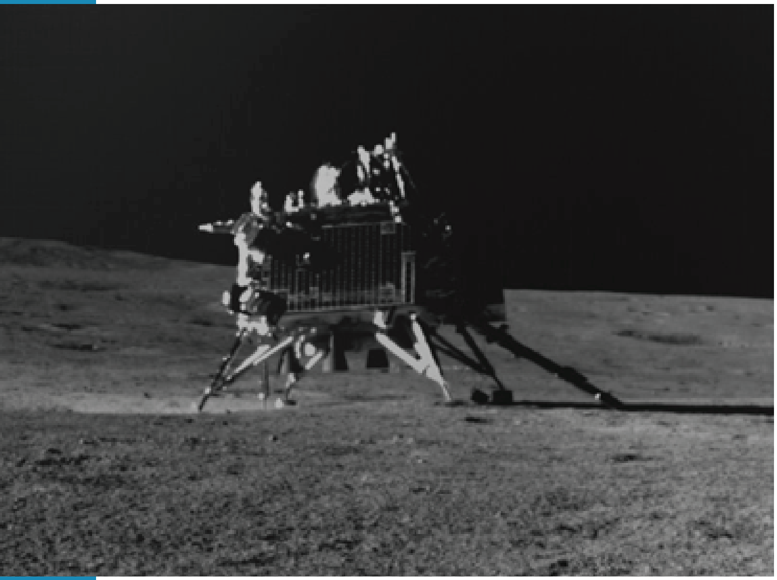
Puerto Rico's Arecibo Observatory, which collapsed in 2020, officially ceased scientific activities Aug. 14, 2023. The owner, the National Science Foundation, plans to convert it into an educational center.

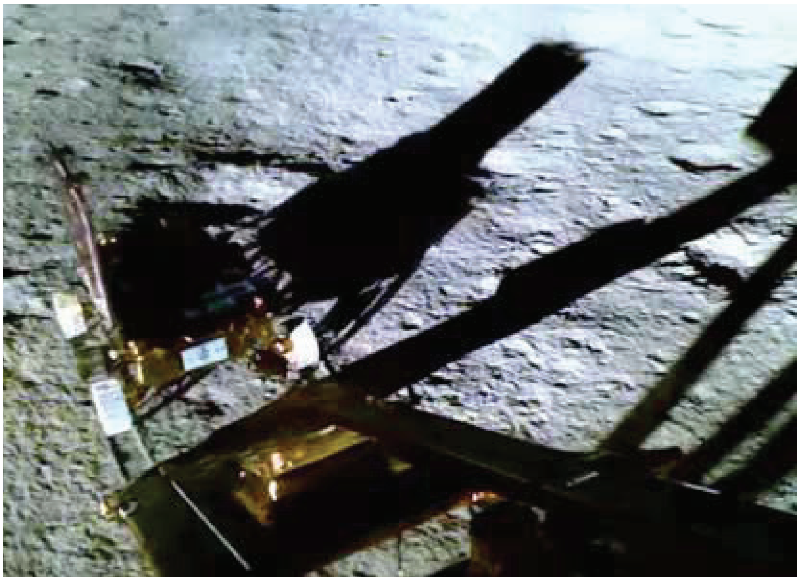
LENSED SUPERNOVA

Using multiple telescopes across the globe, astronomers have detected a supernova in a galaxy 4.5 billion light-years distant that appears lensed into four images due to the gravity of a foreground galaxy bending its light. This gravitational lensing has magnified the supernova, SN Zwicky, by a factor of 25, opening a window into the distant universe.

INDIA MAKES HISTORY WITH MOON LANDING

The fourth country to land on the Moon is also the first to land near the strategic lunar south pole region.





LEFT: HOME BASE. The Pragyan rover took this image of the Vikram lander Aug. 30, a week after the pair touched down. ISRO

RIGHT: WHEELS ON THE GROUND. The Pragyan rover rolls onto the lunar surface a day after touchdown. ISRO

» On Aug. 23, 2023, the Indian Space Research Organisation's (ISRO) Chandrayaan-3 mission landed near the Moon's south pole. A day later, the mission's rover took a walk on the lunar surface.

The lunar excursion was a milestone for India's burgeoning space program, following lunar visits by the U.S., Russia, and China. "The country has now joined a select club of nations that have achieved this technically difficult feat," says Richard de Grijs, professor for the School of Mathematical and Physical Sciences for Macquarie University in Sydney. On top of that, Chandrayaan-3 is the first ever mission to successfully land in the southern polar region of the Moon, doing so just days after a landing attempt in the same region by a Russian craft went awry.

India is the first country to land on the Moon since 2020, when China's Chang'e 5 visited our satellite to collect lunar surface samples. It was ISRO's second attempt at the feat: Four years ago, Chandrayaan-2 entered into lunar orbit but the lander and rover crashed into the Moon's surface. (The orbiter remains operational.)

Chandrayaan-3 launched into orbit July 14 from the Satish Dhawan Space Centre on the island of Sriharikota, off the coast of India. Over the next two weeks, the craft performed multiple maneuvers to raise its orbit around Earth before finally setting sail for the Moon early on Aug. 1, India Standard Time. On Aug. 5, it entered lunar orbit and began the reverse process — a series of engine burns to reduce its altitude. Twelve days later, the Vikram lander, carrying the Pragyan rover, separated from its propulsion module. And on Aug. 23, Vikram made a soft landing roughly 370 miles (600 kilometers) from the lunar south pole. Pragyan rolled out of the lander the following day.

Over the next 14 days, or one lunar day, the pair took scientific measurements, probing the Moon's surface plasma density, thermal properties, soil composition, and internal activities. On Aug. 26, a seismometer on the lander detected vibrations that may be a natural moonquake.

The region near the Moon's south pole is of particular interest because scientists think it houses more water ice across its rugged terrain than previously explored areas of the Moon. "That might give us new insights into the formation of the lunar surface and the internal processes that operated much earlier during the Moon's lifetime," says de Grijs. It also makes the region attractive for human exploration; NASA's Artemis program plans to establish a base in the area.

A NEW MOON RACE

A Russian mission, Luna 25, launched on Aug. 10 with the same goal as

Chandrayaan-3: to land in the southern polar region. However, on Aug. 19 an “abnormal situation occurred,” according to a translated news release. The craft then lost contact with ground control and crashed on the lunar surface.

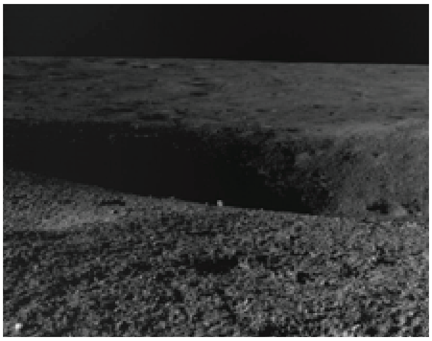
According to Roscosmos, the cause was a technical glitch; the space agency is investigating the incident. The last time Russia (at the time the Soviet Union) visited the Moon was in 1976, with Luna 24.

Despite the loss of Luna 25, Russia continues to plan for future Moon missions, including Luna 26 (also called the Luna-Resurs Orbiter) in 2027 and Luna 27 (the Luna-Resurs Lander) in 2028. It is unclear whether these will be pushed back in order to reassess the mission hardware.

Roscosmos and ISRO’s missions are just the start of what could be a new space race.

“We will no doubt see more such efforts from a range of established and emerging spacefaring nations, not least from Japan in the near future, and with a particular focus on landing near the Moon’s south pole,” says de Grijs. The Japanese Aerospace Exploration Agency (JAXA) launched a Moon lander called the Smart Lander for Investigating Moon (SLIM) on Sept. 7, hitching a ride with the X-Ray Imaging and Spectroscopy Mission, an X-ray telescope. SLIM is scheduled to attempt a precision landing near the Moon’s equator in early 2024. JAXA is also collaborating with ISRO to launch the Chandrayaan-4 mission as early as 2026.

NASA’s plans also continue to move forward, with its Artemis 2 mission scheduled for November 2024. This will mark the first time astronauts will venture around the Moon in over 50 years. The flight is intended to pave the way for the crew of Artemis 3, scheduled for 2025, to explore the Moon’s South Pole. This would also be the first time anyone has set foot on the lunar surface since 1972. However, that goal depends on SpaceX’s development of its Starship-based lander, which will ferry NASA crews to the surface. —SAMANTHA HILL



RIM SHOT. On Aug. 27, the Pragyan rover took this photo as it approached the edge of a 13-foot-wide (4 m) crater. ISRO

Boulders fly from Dimorphos

IMAGE: NASA, ESA, DAVID JEWITT (UCLA). IMAGE PROCESSING: ALYSSA PAGAN (STSCI)

When NASA’s Double Asteroid Redirection Test (DART) smacked into the asteroid Dimorphos on Sept. 26, 2022, it didn’t just change the trajectory of the asteroid. It also flung a few dozen boulders from the surface into space, which now surround the asteroid in a slowly expanding swarm. The Hubble Space Telescope revealed this boulder cloud in images taken four months after the impact. Scientists identified 37 boulders in all, ranging from 3 feet (1 meter) to 22 feet (7 m) across, or about 0.1 percent of the entire mass of Dimorphos. They are leaving the asteroid behind at a speed of just over a half-mile (0.8 kilometer) per hour, and are some of the faintest objects ever imaged inside our solar system. —MARK ZASTROW

QUICK TAKES

BLAZING BROWN DWARF

As failed stars, brown dwarfs are normally cool objects. But one has been found with a dayside temperature of 14,000 F (7,700 C) — hotter than the Sun — thanks to radiation from a neighboring white dwarf. The system could offer insight into ultra-hot Jupiters orbiting very close to their host stars.

LOCAL MEASUREMENTS

Researchers have proposed measuring the dark energy within our galactic neighborhood by observing the orbits of the Milky Way and Andromeda galaxies, which are on a collision course. Observations of Andromeda’s mass and motion from JWST will help fine-tune the measurements.

SECURITY ALERT!

The U.S. National Optical-Infrared Astronomy Research Laboratory announced it had suffered a “cyber incident in its computer systems” on Aug. 1. This forced a shutdown of the 8-meter Gemini North and South telescopes, along with smaller telescopes in Chile. As of early September, the scopes are still offline.

PASSBAND INTERFERENCE

A study has found that SpaceX’s Starlink satellites emit unexpected radio interference at wavelengths outside their assigned bands. If not curbed, this unintentional radiation from tens of thousands of planned satellites could make some astronomical observations impossible.

DUSTY ISS

The “household” dust that accumulates on the International Space Station contains several types of harmful chemicals — including so-called forever chemicals — at levels higher than in homes on Earth. The compounds may originate from flame-retardant and waterproof coatings used to reduce fire risk and control moisture onboard. —DANIELA MATA, M.Z.

Bizarre star may one day become a magnetar

THE RIGHT STUFF. HD 45166 is a star with the characteristics needed to one day go supernova and possibly turn into a magnetar. In the background of this illustration (at upper left) lies HD 45166's companion, a more typical blue star. ESO/L. CALÇADA

SOME 3,000 LIGHT-YEARS AWAY in the southern constellation Monoceros lies a peculiar star in the binary system HD 45166. Long considered a misfit, it is rich in helium and sports unusually powerful winds for its rather humdrum size of 2 solar masses. New observations published Aug. 17 in *Science* have revealed it also has an extraordinarily strong magnetic field.

And this, in turn, may prove to be the key to an even greater mystery: the origin of magnetars, a rare class of neutron stars that are the strongest magnets in the universe. According to models, HD 45166 has the right combination of mass and magnetic field to one day go supernova and leave behind such a highly magnetic neutron star. That makes the star a possible magnetar progenitor, the first known of its kind.

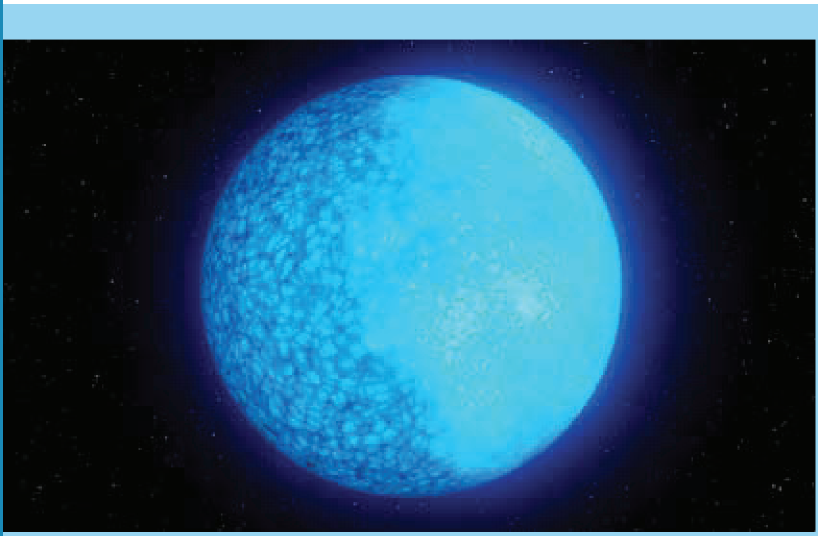
"We've never detected a magnetic field in a massive helium star that will undergo core collapse," says Tomer Shenar, first author of the new study and an astronomer at the University of Amsterdam. "It's really a new type of star."

HD 45166 is an unusual member of an exclusive family called Wolf-Rayet stars. These stars are usually up to 25 times more massive than the Sun, shining a million times brighter and expelling powerful stellar winds. But HD 45166 is a relative lightweight. The fact that it still produces torrential stellar winds is what initially drew Shenar's attention, he says. "I was going through all the literature wondering, 'What can it be?' and remember sitting at my desk and thinking, 'Wait, what about magnetic fields?'"

Shenar and his colleagues used the Canada-France-Hawaii Telescope atop Maunakea, which is equipped with a spectropolarimeter, an instrument that can measure magnetic fields. The observations confirmed Shenar's suspicions: HD 45166 has a magnetic field of an astounding 43,000 gauss — about 100,000 times stronger than Earth's magnetic field, and the most magnetic massive star found to date.

The team's calculations of the star's evolution indicate it will explode as a supernova and collapse into a neutron star just 8 miles (13 kilometers) wide. When it does, its magnetic flux will be conserved, like the angular momentum of an ice skater pulling in their arms to spin faster. This effect will multiply the field strength some 10 billion times, turning the star into a magnetar.

"As a laboratory for very strong magnetic fields, this star offers us something that we simply cannot mimic or study elsewhere," says Shenar. —RANDALL HYMAN



DUAL NATURE. The peculiar "two-faced" white dwarf Janus, shown here in an artist's conception, lies 1,300 light-years away in the constellation Cygnus. K. MILLER, CALTECH/IPAC

A TWO-FACED WHITE DWARF

Astronomers have discovered an extremely rare white dwarf composed of two halves: One side contains almost pure hydrogen and the other half helium. The unprecedented find, published July 19 in *Nature*, has been nicknamed Janus after the two-faced Roman god who represents duality. The team suspects that an uneven magnetic field is to blame. It may be preventing hydrogen and helium from mixing vertically on one side and causing hydrogen to float to the top. Alternatively, the magnetic field may be lowering the gas pressure (while increasing the gravity) in some regions of the star's atmosphere, allowing a hydrogen "ocean" to form above the denser helium. —D.M.

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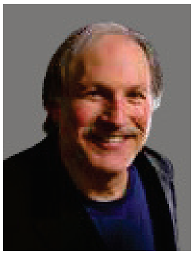
Empty conclusions

There's a lot of space in space.

Alpha Centauri (the yellow star just to the right of center) is the closest bright star to Earth. At 4.35 light-years away, on a scale model where Earth is the size of a bacterium, this star would sit 4.34 miles (nearly 7 km) distant. ALAN DYER



BY BOB BERMAN
Bob's recent book, Earth-Shattering *(Little, Brown and Company, 2019), explores the greatest cataclysms that have shaken the universe.*

In astronomy, we tend to use miles or kilometers for nearby objects like the Moon and Venus, and light-years or parsecs for star distances. *Parsec* is street slang for professional astronomers but usually bewildering to the public, since it's based on angles rather than tape-measure-like distances. So, visualizing cosmic vastness starts with tackling that term from a new angle.

Your traveler's guide to parsecs begins by noting that two Moon-widths subtend a 1°-wide angle on the sky. And 90° is the distance from the horizon to the zenith overhead. Easy, so far. If we sliced the Full Moon into 30 equal sections, each would be 1 minute of arc (1'). That angle also happens to be the human 20/20 visual resolution limit. It's the angular separation between markings that distinguish an F from an E on the Snellen eye chart. One arcminute is also roughly the diameter of Venus when it's closest to us, like when it transits the Sun.

A huge lunar crater 72 miles (116 kilometers) across appears 1⁄30 the Moon's diameter, or again 1'. But a crater only about a mile (1.6 km) wide takes us to our next important unit, the arcsecond ("), roughly the visibility limit of backyard telescopes. We astronomers grew up with arcseconds as easily as learning our ABCs. We use the measurement routinely to express close separations. For example, the colorful components of the gorgeous double star Albireo are 34" apart. Still, an arcsecond is a truly tiny angle — the width of a dime as seen from 2.5 miles (4 km) away.

It's also the average gap between the Sun and Earth if viewed from 3.26 light-years away, making that distance special enough to merit its own term: a *parsec*.

Now comes the good stuff, which uses that Earth-Sun separation of 93 million miles (150 million km), commonly called an astronomical unit or AU. As it happens, there are about 63,000 AU in a light-year. And there are also very nearly 63,000 inches in a mile. That coincidence offers a surprising scale model for illustrating celestial distances.

Start by representing our Sun as the period at the end of this sentence. In reality, more than a million Earths could fit inside a hollow Sun. But if the Sun is the size of that dot, then Earth would only boast the size of a bacterium and be located 1 inch (2.54 centimeters) away. Now let's enter our model. We'll gaze at the cosmos from our microscopic planet and ponder the distance to the nearest bright star, Alpha Centauri.

It's 4.35 light-years away in real life, which equals about 275,000 AU. Using our scale model, Alpha Centauri would be a dot 275,000 inches (698,500 cm) from our tiny Earth, which works out to 4.34 miles (6.985 km). Same number! If you're still with me, you've seen that if the Sun is the period at this sentence's end, the nearest star is a duplicate dot 4.34 miles away. We're now understanding celestial architecture as a realm of astounding, breathtaking, inconceivable emptiness.

Let's let this sink in. If we represent Earth as a microscopic bacterium, the Sun is a decimal point 1 inch from it, and the stars are dots a few miles apart. The main point is that when Earth is the size of a germ, then on that scale, any object's distance in light-years can be accurately represented using that same figure in miles. (Of course, it doesn't work out as neatly in kilometers.)

A scale model of our cosmos is still astronomical in size.

Here's what's truly amazing. On that scale, the nearest spiral galaxy would lie 10 times farther than the real distance between Earth and the Moon. And the closest galaxy cluster, the Virgo group, would sit among the asteroids of the main belt.

The takeaway: Even if you represent Earth with something too small to be visible, a scale model of our cosmos becomes astronomical in size.

And a second takeaway: This model only attempts to visualize the known, visible universe. Cross over to the unobservable (but majority) of the cosmos, where infinity possibly prevails, and everything on this page might get tossed into a wastebasket labeled "hopeless understatement."

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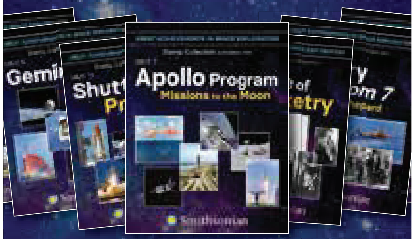

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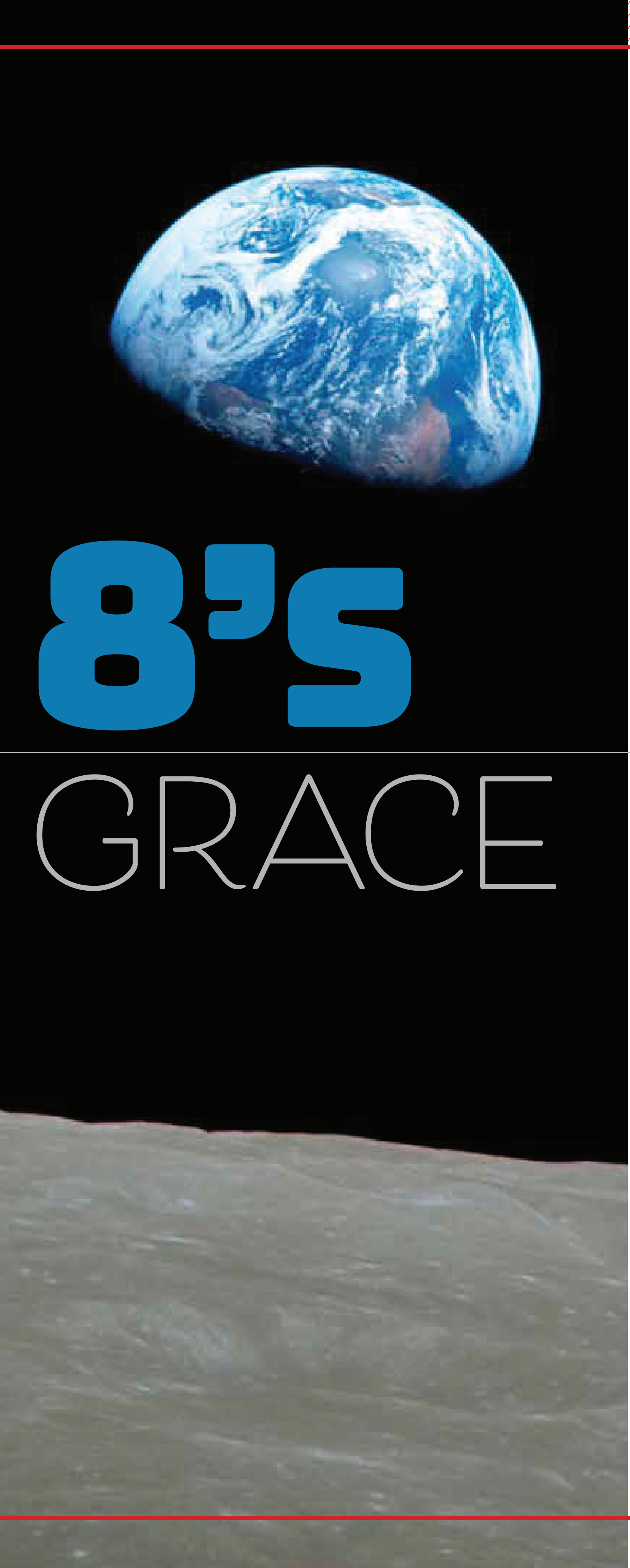
APOLLO

MOMENT OF

Bill Anders' famous photograph of Earthrise became an iconic image of the Space Age — and a clarion call to the emerging environmental movement. NASA

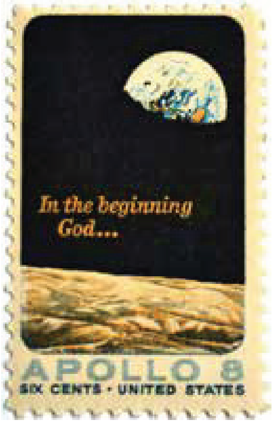


8's GRACE

In the first broadcast from lunar orbit, Apollo 8's moving reading from Genesis made a lasting cultural impact.

BY ALLYSON GROSS AND JENELL JOHNSON

AS EUGENE CERNAN took his last steps on the lunar surface, the Apollo 17 commander promised to come back. "As we leave the Moon at Taurus-Littrow," Cernan said Dec. 13, 1972, "we leave as we came and, God willing, as we shall return, with peace and hope for all mankind." It was a callback to a plaque left behind at the base of the Apollo 11 Lunar Module, which stated that the men from planet Earth who had first set foot upon the Moon "came in peace for all mankind."



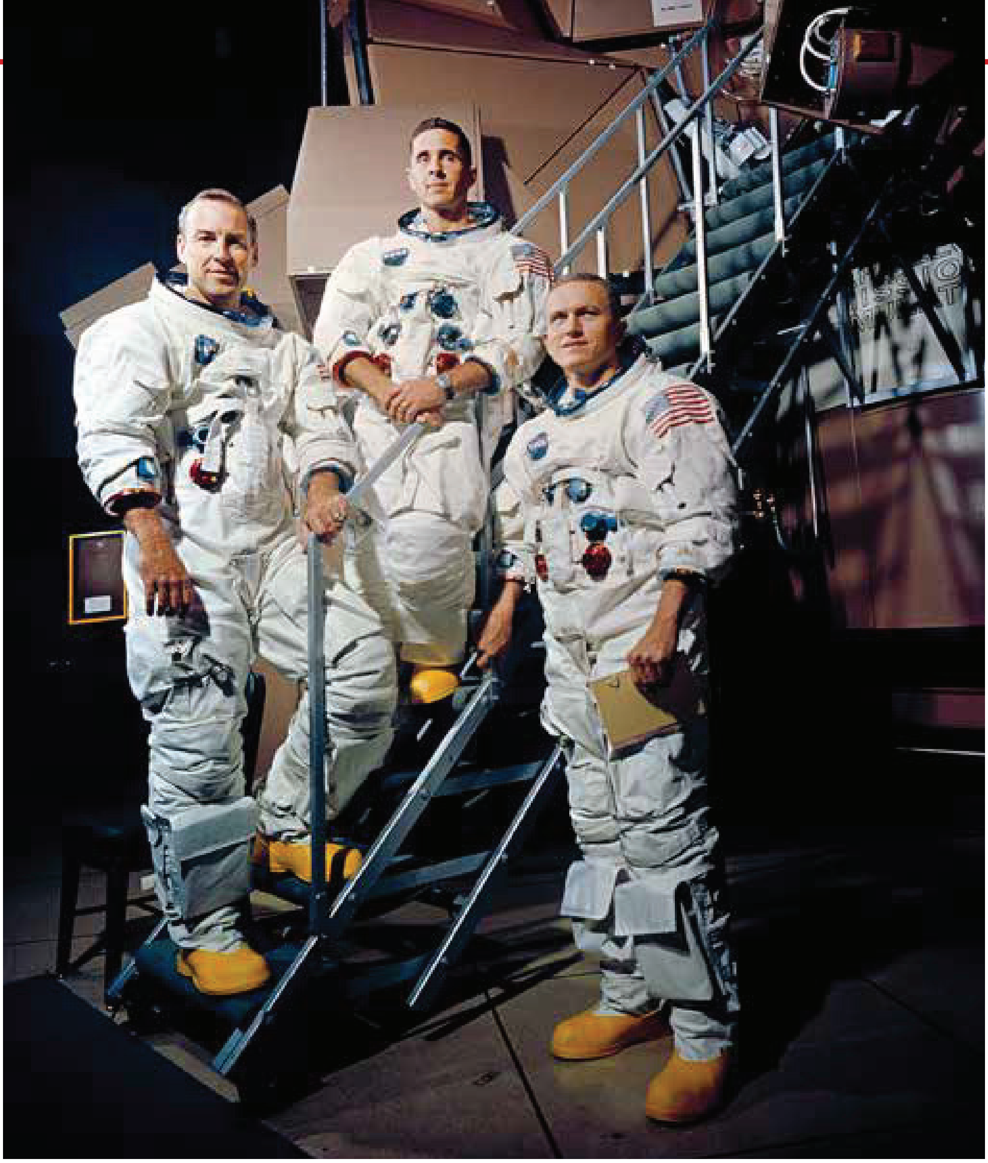
The stamp issued in 1969 to commemorate Apollo 8 combined two iconic pieces of the mission's legacy: the reading of Genesis and Anders' "Earthrise" photo.
UNITED STATES POST OFFICE DEPARTMENT

But others came peacefully first. Although it left no trace upon the pocked, lonely surface of the Moon, the Apollo 8 mission of December 1968 proved that getting there was possible.

Apollo 8 was crewed by Commander Frank Borman, Command Module Pilot James "Jim" Lovell, and Lunar Module Pilot William "Bill" Anders. The three astronauts were the first to be lofted by Wernher von Braun's Saturn V rocket. In quick succession, they also became the first to leave Earth's orbit, to enter the orbit of another celestial body, and to gaze upon the farside of the Moon.

While often overshadowed by the giant leaps of the missions that followed, Apollo 8's legacy is vast. Perhaps the most well-known artifact from the mission, the famous "Earthrise" photo taken by Anders, is credited with catalyzing the modern environmental movement. Apollo 8's timing — over Christmas at the close of a tumultuous year — has further imbued the mission with a kind of mythical quality.

Nothing contributed more to this quality than the astronauts' inspired choice to close their Christmas Eve television broadcast by reading the opening



ABOVE: The crew of Apollo 8 pose outside a simulator at the Kennedy Space Center. From left to right: James A. Lovell Jr., William A. Anders, and Frank Borman. NASA

ABOVE CENTER: Lovell points to the line in his bound flight plan where he began his section of Apollo 8's reading from Genesis. This picture was taken at the National Cathedral in Washington, D.C., in December 2018, at an exhibit organized by the Smithsonian for the mission's 50th anniversary. NASA/JOEL KOWSKY

verses from the Book of Genesis. The reading served as a benediction, consecrating the endeavor of space exploration and projecting a sense of optimism and renewal to a global audience. According to a telegram from one grateful viewer, the mission "saved" 1968.

Earlier this year, we visited Lovell, now 95, at his residence outside Chicago. With the mission's anniversary upon us, we set out to explore the legacy of Apollo 8 with one of the three men who know it best.

LUCK OF THE DRAW

Fifty-five years later, what Lovell remembers best about Apollo 8 was its timing — one of many lucky draws that would come to define his career. His selection for the mission was a fluke of astronaut scheduling and NASA's own shifting timelines. First assigned to the backup crew of Apollo 9, Lovell was shifted to its prime crew, and then 9's crew was swapped for 8. "The timing just came into being," Lovell says. "It happened that Apollo 8 was ready to go to the Moon, and it happened also that we had to do a flight around the Moon before we could attempt a landing. … We were all interested in seeing if we could make it all the way," he says.

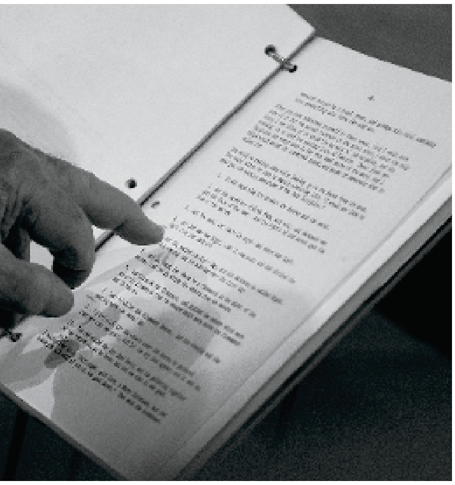
Apollo 8 went off without a hitch and paved the way for future successes. "Apollo 11 was merely confirming in real time all the stuff that we had done except the actual landing," Lovell notes. The "actual landing" was a triumph. But Lovell knows that landing isn't all there is. Indeed, thanks to the near catastrophe of Apollo 13, he is the only person to twice circumnavigate the Moon but never set foot upon it.

As a year of political upheaval, 1968 is remembered primarily for unrest both domestic and international. In 1968, more U.S. soldiers died in Vietnam than in any

ADVICE FROM CAPTAIN LOVELL

Artemis 2, the first crewed mission of NASA's Orion spacecraft, is scheduled to launch in November 2024. It will be the first mission to return to the Moon since Gene Cernan's promise to do so nearly 50 years prior. Like Apollo 8, it is the first of its program to carry astronauts to the Moon. And, like 8, it will not land. Instead, it will test the equipment, systems, and techniques necessary for the missions that follow.

Apollo 8 was a mission of firsts. But although it will trace its path, Artemis 2 offers a different set of firsts: Its crew will feature the first woman, the first person of color, and the first non-American to embark on a lunar mission. We asked if Lovell had any words of advice for this "new generation of star sailors and dreamers," as NASA Administrator Bill Nelson has called them. While Lovell — perhaps more than anyone — knows firsthand the dangers of space exploration, he replied only with characteristic humor. "Well, first of all, do they really want to make the trip? Sometimes when you're finally sitting in the spacecraft and hearing [the] countdown, [you think,] 'Why did I get into this?'"



year before or after; on U.S. soil, the assassinations of Rev. Martin Luther King Jr. and Robert F. Kennedy further destabilized an already fractured homefront.

But in a year plagued by violence, Apollo 8 went to the Moon in peace. Its success was proof, in the words of Anders' wife, Valerie, "that we could do something besides go to war; we could do something positive with our technology." For their efforts, the crew were named *Time* magazine's Men of the Year. "For all its upheavals and frustrations," *Time* proclaimed, "the year would be remembered to the end of time for the dazzling skills and Promethean daring that sent mortals around the moon."

In hindsight, the idea that a lunar flyby might dull the sting of nearly 17,000 U.S. soldiers dead in Vietnam might be a reach.

CLAIMS THAT APOLLO 8 "SAVED" THE YEAR FROM RUIN ARE SUBJECTIVE. BUT THERE IS NO QUESTION THAT THE MISSION DID UNITE PEOPLE AROUND THE GLOBE.

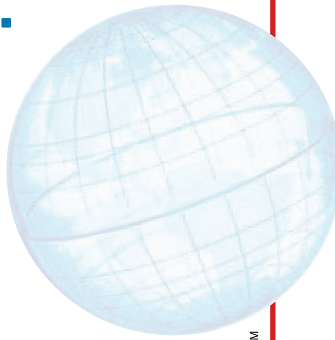
Claims that Apollo 8 "saved" the year from ruin are subjective. But there is no question that the mission *did* unite people around the globe. Over the course of the weeklong mission, the crew of Apollo 8 broadcast live a total of six times. These broadcasts were the first to televise from the realm of another planetary body and brought images of the Moon into living rooms worldwide.

The astronauts were told that their broadcasts would have a large audience. But with so little precedent, they had no idea how far their words would reach. "Naturally, I didn't know how many people [were watching]," Lovell says. For the Christmas Eve broadcast, viewership estimates claim that anywhere from half a billion to a billion people — 1 in every 4 people on Earth — tuned in live. When we told Lovell this, he laughed, rendered speechless by its magnitude more than half a century later: "I can't talk!" In the lead-up to the mission, what preoccupied the crew most was not the number of viewers, but what to say to whoever did tune in. "This was the first flight to the Moon," Lovell says. "We were saying to ourselves, 'What can we do? What can we say back to the people on Earth?' "

BEGIN AT THE BEGINNING

Tasked by NASA Public Affairs Officer Julian Scheer with finding something "appropriate" to say for the historic broadcast, Borman was stumped. He hadn't even wanted to take the 12-pound (5.4 kilograms) television camera on the flight, a situation in which every ounce was counted. However, while NASA usually gave the mission commander the final say, this was one decision where Borman was overruled. He would later concede that NASA had been right: In the eyes of the public, Apollo 8 would become inextricably linked with the words and images broadcast that Christmas Eve.

"This is Apollo 8, coming to you live from the Moon," Borman introduced the staticky broadcast, accompanied by grainy black-and-white footage of the lunar surface. The astronauts then took turns narrating what viewers were seeing, serving as the Moon's first tour guides. In addition to naming the bumps, craters, and mountains crossing the screen, the men also described their emotional impressions of the alien surface. For Borman,



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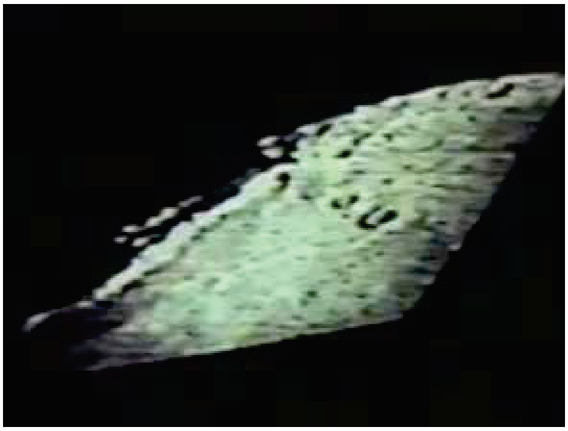
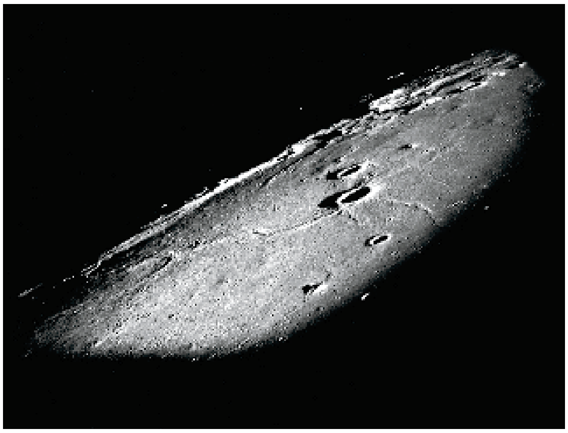
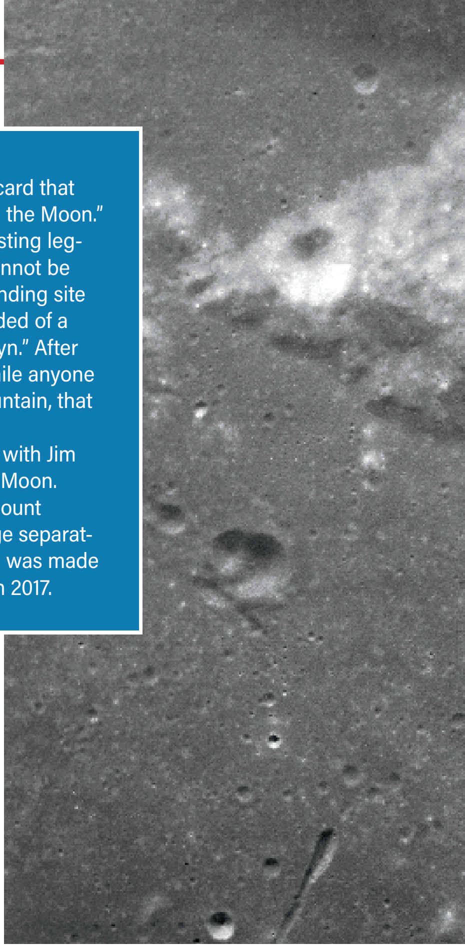




LEFT: Toward the end of Apollo 8's Christmas Eve broadcast, the crew flew over the Sea of Tranquillity as they neared the lunar terminator. Though the broadcast image quality was limited (as seen in this broadcast screen capture), viewers could see the impressive lunar terrain by the stark shadows it cast. NASA

RIGHT: This higher-quality view of the same landscape was taken by the crew with a Hasselblad camera. The largest crater visible is Sinus, with Sinus E directly behind it and Sinus A in the foreground. NASA



TOP CENTER: Mount Marilyn stands out at upper left in this photograph taken from Apollo 10. NASA

A GIFT FOR ETERNITY

Apollo 8 launched Dec. 21, 1968, and splashed down in the Pacific just under one week later. While the timing may have worked best for NASA — and offered a catchy public framing — it was less than ideal for the families of the astronauts. "Of course, we were all really young," recounts Susan Lovell, who was 10 years old at the time of the mission. "Our dad was just off doing his job."

It also posed a dilemma for Lovell: What's a dad and husband to do when he's 240,000 miles (386,000 kilometers) away at Christmas? The role was clearly on his mind. Following the trans-Earth injection burn that sent the crew home, his first words back to Houston, in the wee hours of Christmas Day, were: "Please be informed there is a Santa Claus." And on Christmas morning, he had a mink coat delivered to his wife Marilyn at their southeast Houston home with a card that read, "Merry Christmas and love, from the man in the Moon."

The mink is still in the Lovell family, but the lasting legacy of Lovell's 1968 Christmas gifts to Marilyn cannot be held or worn. As the crew flew over the future landing site of Apollo 11, Lovell surveyed the terrain and decided of a particular peak, "Well, I'll name that Mount Marilyn." After the crew of Apollo 11 used the name, it stuck. While anyone might buy a coat for their wife, giving her "a mountain, that was something different," Lovell says.

Marilyn passed away Aug. 27, 2023, at age 93, with Jim at her side. But she remains immortalized on the Moon. Topographical maps of the lunar surface show Mount Marilyn within Montes Secchi, the mountain range separating the seas of Tranquility and Fertility. The name was made official by the International Astronomical Union in 2017.

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the Moon was a "vast, lonely, forbidding-type existence or expanse of nothing." For Lovell, it made Earth look like a "grand oasis in the big vastness of space." Anders commented on the lunar sunrises and sunsets, the "long shadows" and "stark terrain."

To close, Borman announced that the crew had a final message for the people of Earth. And then each man took turns reading the first 10 verses of the book of Genesis.

The story of how Borman decided on the reading has also become part of the mission's mythos. Some accounts have suggested that the reading was a spontaneous decision by the astronauts on the flight; others reported that the idea was hatched by Borman's friend, NASA colleague, and fellow church member Rodney Rose.

The real story is a little more complicated. Borman initially approached his crewmates for their thoughts about what to say; both Anders and Lovell came up blank. He then reached out to his friend Simon Bourgin, who worked for the U.S. Information Agency, and Joe Laitin, a public affairs officer who worked for presidents John F. Kennedy and Lyndon B. Johnson. It was Laitin's wife Christine — a member of the French resistance during World War II — who came up with the idea to read the first 10 lines of Genesis, which detail the Judeo-Christian account of the creation of Earth. "Why don't you begin at the beginning?" she suggested.

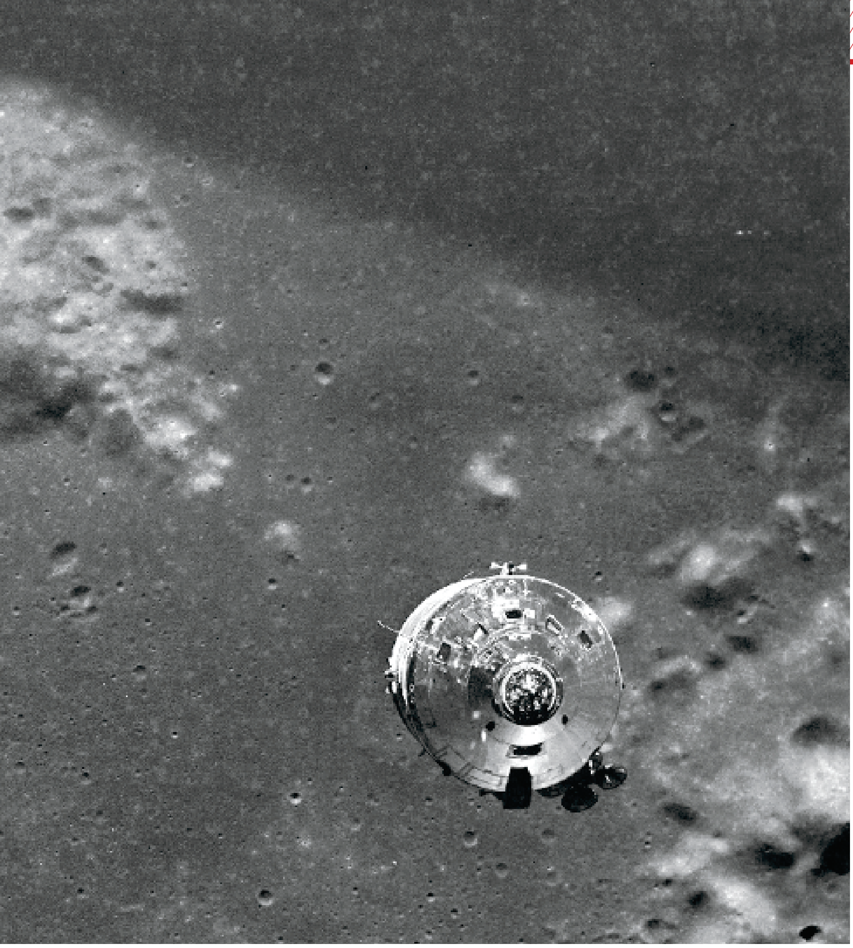
The astronauts agreed. "We all decided that this was really good," Lovell told us. "It turned out to be quite appropriate, I think." After all, Lovell notes, "[it was] Christmas. We thought that the message that it portrayed was at the right time."

CBS anchor Walter Cronkite agreed. In an interview with PBS, Cronkite later recalled that when the astronauts began the reading, his first impression was that it was "too much" and maybe even a little "corny." But by the end, the famously taciturn newsman had tears in his eyes. "It was really impressive and just the right thing to do at the moment. Just the right thing," Cronkite said.

CATALYST FOR CHANGE

There were Americans who disagreed — a few vehemently. The atheist activist Madeline Murray-O'Hair, who came to

BELOW: Lovell grins as he discusses with the authors Apollo 8 and his NASA career. MARK ZASTROW

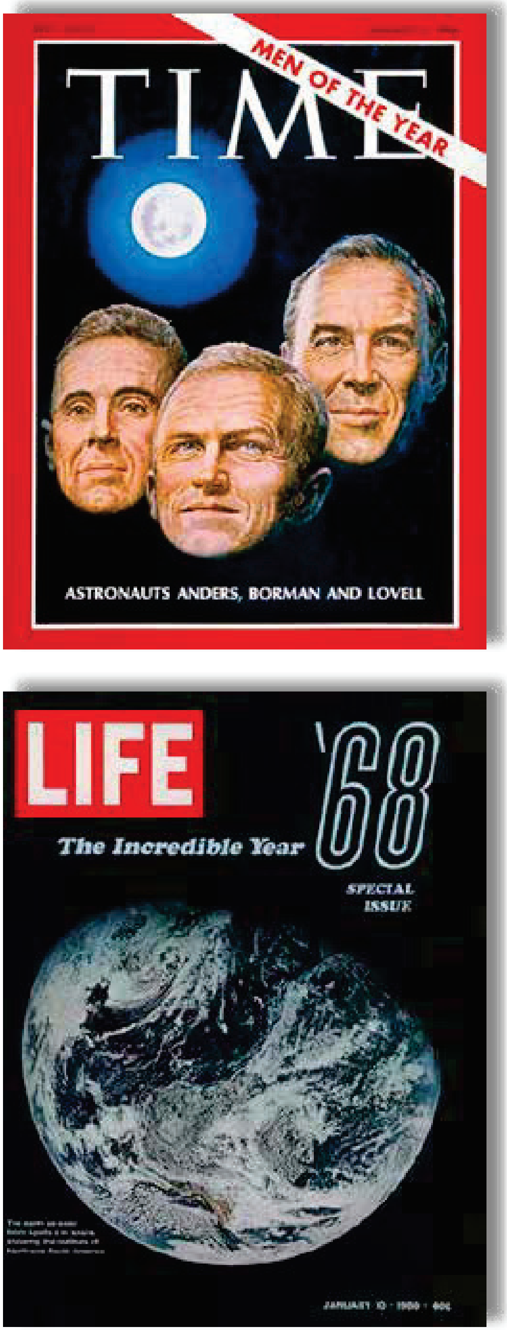


prominence in 1963 for her successful campaign to remove mandatory prayer and Bible readings from U.S. schools, complained that the reading was “ill advised” and “most unfortunate.” In an interview with a Texas radio station, O’Hair encouraged listeners to write to NASA denouncing the reading as a violation of the separation of church and state. “She didn’t like anything if it had something religious to it,” Lovell says. She later filed a lawsuit on the matter, which was dismissed.

O’Hair’s request resulted in nearly 30,000 letters complaining about the reading. However, it also inspired a massive counter-campaign to support the astronauts. Dubbed Project Astronaut, the campaign was organized by national religious organizations and local churches, whose members wrote more than 8 million letters from 1969 to 1975 framing the event as a matter of religious freedom. Many of the letters were sent to NASA and Lovell’s house in Houston. Sometimes, people would even send letters addressed to the Apollo 8 spacecraft itself. “We tried to answer them the best we could,” Lovell says.

Those in support of the Genesis reading ultimately won out. On the Apollo 8 commemorative stamp issued in May 1969, the words “In the beginning God…” — the opening line of Genesis — accompany the famous Earthrise image taken by Anders. This image of Earth, the first of its kind taken by a human from space, is rivalled only by Apollo 17’s “Blue Marble” photograph of the whole Earth as one of the most impactful visuals of the Space Age. While Apollo 8 might not have landed on the Moon, its television broadcasts and photographs brought home both the sight of the lunar landscape and a new perspective on Earth.

Astronauts experience what has come to be called the overview effect, a term coined by space philosopher Frank White to describe the shift in perspective and priorities afforded by viewing Earth from above. In the “big vastness of space,” earthly differences are made to seem small. “The vast loneliness up here of the Moon is awe-inspiring,” says Lovell. “It makes you realize just what you have back there on Earth.”



TOP AND ABOVE: Apollo 8 and its crew immediately became symbols of the year 1968. TIME/LIFE

Allyson Gross *is a Ph.D. candidate in Communication Arts — Rhetoric, Politics, and Culture at the University of Wisconsin-Madison.* **Jenell Johnson** *is a professor of Communication Arts at UW-Madison. Her most recent book is* Every Living Thing: The Politics of Life in Common.

I have just replaced Albert Einstein (A.D. 1879–1955) with Pythagoras (570–490 B.C.) as the one person, living or dead, with whom I would like to have dinner.

That is quite a turnaround for me, since his Pythagorean theorem was the reason I failed my 10th-grade geometry class. It was enough to scare me away for years — and keep me from learning about a man considered a giant in the early studies of math, music, philosophy, *and* astronomy.

But since my main two hobbies in high school were astronomy and music, I wish my teacher would have shared with me that Pythagoras is the man who coined the term *cosmos* and was instrumental in the development of understanding the physics of musical sound.

The overtone series

Among his many accomplishments, Pythagoras is credited with the discovery and understanding of the overtone series — the series of frequencies contained in most musical notes, creating the distinctive sound you hear. Before I was introduced to the overtone series, I had taken musical pitch at face value without knowing it takes a series of mathematically related tones to create what I heard as familiar and pleasing. After I learned about overtones, I never listened to music in the same way.

In his 1619 book *Harmonices Mundi* (*Harmony of the World*), Johannes Kepler (1571–1630) describes Pythagoras passing through a smithy and noticing that hammers of different sizes created sounds with different pitches on the anvil. Pythagoras then moved from hammers to strings, observing how different lengths of string oscillated at different frequencies, producing various tones. (Today, this exact story is considered apocryphal; likely Pythagoras made this discovery using only strings, no smithy required.)

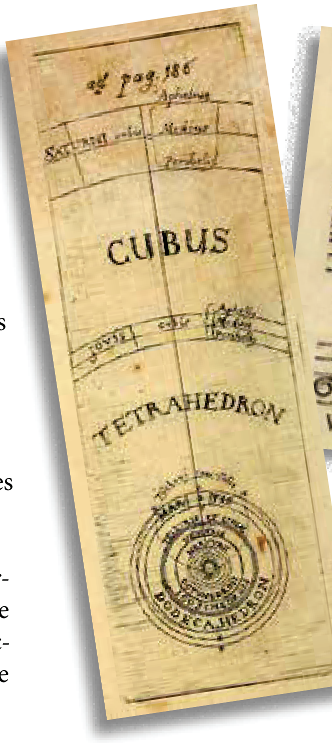
Regardless of the chain of events, Pythagoras discovered that when a musician plays a note and causes a musical instrument to vibrate, the root note that we hear (called the fundamental or first

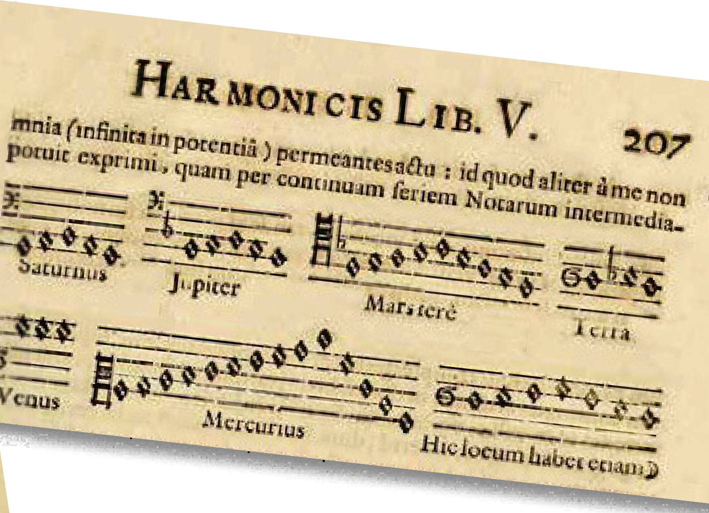
The soundtrack of the universe

Early philosophers and astronomers strove to understand the harmonies of our solar system. Today, scientists hunt for cosmic tones of a different kind. **BY DAVID GROSSMAN**

Dishes of the Karl G. Jansky Very Large Array in New Mexico line up beneath the starry sky. Radio waves are just one of the numerous signals from space that comprise the soundtrack of the cosmos. NRAO/AUI/NSF, JEFF HELLERMAN

harmonic) is also accompanied by a series of higher frequencies. These occur naturally in a strict mathematical sequence and depending on the strength of the overtones that occur above the fundamental, produces the tone and character of an instrument — which is also referred to as timbre. Without those overtones, the result would be a very unsatisfying sine wave. Pythagoras identified these overtones as harmonic frequencies using mathematical ratios. One-half of the fundamental (1:1) creates an octave (2:1) above the original pitch, with the third overtone — the perfect fifth — vibrating at three times that of the fundamental above the second overtone (3:2), and so on. This sequence





HARMONICIS LIB. V. 207

mnia (infinita in potentiâ) permeantes actu: id quod aliter à me non potuit exprimi, quam per continuam seriem Notarum intermedia-

Saturnus
Jupiter
Mars ferè
Terra
Venus
Mercurius
Hic locum habet etiam

In *Harmonices Mundi*, Johannes Kepler explored in detail Pythagoras' ideas that the planets generate tones and harmonies as they move through the heavens, ascribing scales to each body in the solar system.

HARMONICES MUNDI LIBRI V, JOHANNES KEPLER, SUMPTIBUS GODOFREDI TAMPACHII ..., EXCUDEBAT IOANNES PLANCUS, 1619, CC0 1.0 UNIVERSAL (CC0 1.0), HTTPS://DOI.ORG/10.5479/SIL.135810.39088002800316 continues into ever higher frequencies, eventually beyond what the human ear can detect. An instrument's unique voice comes from the fact that each uses a different combination of frequency strengths to produce the same note.

In other words, the harmonics of the overtone series deliver rich tonal complexities. However, their existence is hidden within the sound we hear in the same way that light we perceive as white combines all the wavelengths of the visible spectrum.

Heavenly motions

Where does this musical finding intersect with the cosmos? Pythagoras took his earthly discovery and sought to connect it to the workings of the sky above. Building on his realization that "there is geometry in the humming of the strings," Pythagoras believed "there is music in the spacing of the spheres" of the planets visible in the sky.

This belief had long-lasting implications: Sixteen centuries later, music, math, and astronomy were complementary studies. Seeking connection between the physical world and the cosmos, Galileo Galilei (1564–1642) stated: "Mathematics is the alphabet with which God has written the universe."

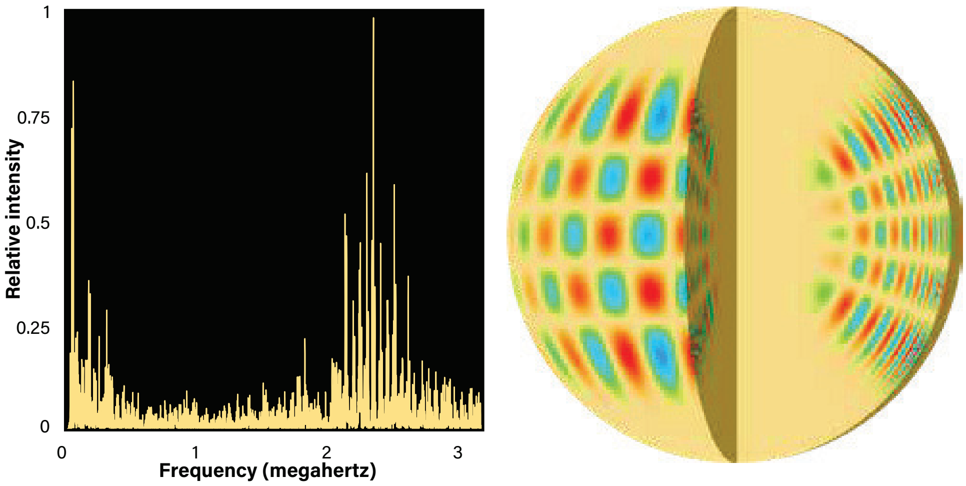
Around the same time, Kepler was attempting to expand Pythagoras' concepts of mathematical ratios and musical intervals (including overtones) in *Harmonices Mundi*, reflecting what he believed was God's design and what the soul naturally senses. "The heavenly motions are nothing but a continuous song for several voices, to be perceived by the intellect, not by the ear," he wrote. His intention was to illuminate how the six known planets of that time orbit the Sun and produce distinctive tones relative to their distance and in harmonic relationship with each other — the "music of the spheres."

Listening to the universe

Pythagoras, Kepler, and others may have professed a musical connection to the cosmos, but current technology provides definitive ways in which sound can show us the stars. In a sense, the rhythmic waves, pulses, and bursts we receive from space are all elements of the soundtrack to our universe.

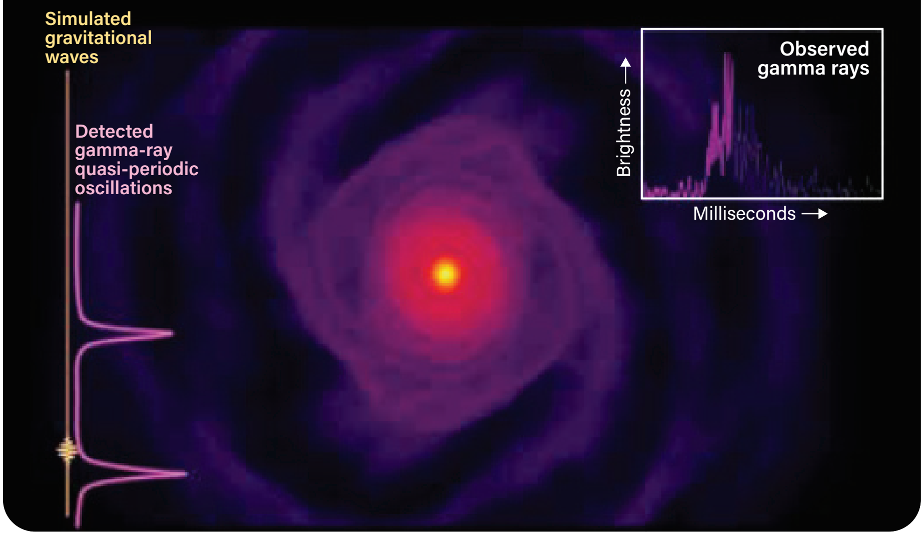
For instance, in 1964, Arno Penzias and Robert Wilson picked up what we now know to be the cosmic microwave background (CMB) radiation, the echo from the Big Bang of 13.8 billion years ago. What first appeared to them as background noise ultimately provided evidence for much of modern cosmology. I find it noteworthy that the term itself, *Big Bang*, implies an explosion of sound, although that could not have happened because what we define as sound is created by vibrating air molecules. This is why screaming in the vacuum of space will not

STELLAR ACOUSTIC SPECTRUM

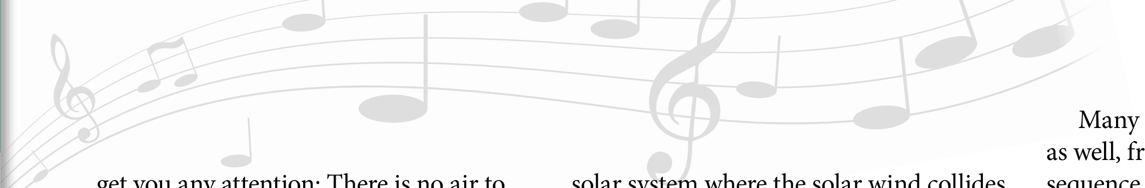


At right, an artist's concept shows how acoustic waves resonate inside a Sun-like star. Red and blue areas represent opposite directions of motion of the stellar material. At left is the "acoustic spectrum" of Alpha Centauri A, showing modes of oscillation within the star. The peaks between about 1.5 and 3 megahertz correspond to pulsations with periods of five to 10 minutes. ESO

A FLICKERING GAMMA-RAY BURST


Simulated gravitational waves
Detected gamma-ray quasi-periodic oscillations
Observed gamma rays
Brightness →
Milliseconds →

This still from a simulation shows the milliseconds following the merger of two neutron stars into a short-lived hypermassive neutron star (HMNS; at center). Such an event generates a burst of gamma rays, whose brightness over time is shown at upper right. The resulting HMNS shakes and jiggles, causing it to emit gamma rays that peak at two broad frequencies, shown as the magenta line at left. Also at left, astronomers simulated the frequencies of gravitational waves given off by the event — a single frame in the model is shown in orange. Like the gamma rays, scientists expect the frequency of the gravitational waves, once observed, to bounce between two peaks. The entire event lasts only milliseconds, after which the HMNS collapses into a black hole. NASA'S GODDARD SPACE FLIGHT CENTER AND STAG RESEARCH CENTRE/PETER HAMMOND



MUSIC NOTES: POKKI/DREAMSTIME.COM

get you any attention: There is no air to transmit the vibration and create sound.

But although the limitations of the human ear require us to rely on processing technology to make that which is inaudible audible, we can still “hear” the extraordinarily low frequencies and respective overtones of the early universe, as captured by satellites such as Planck, through the CMB. The resulting sound is nothing short of mesmerizing.

Our ears are further limited as they can only detect frequencies between 20 and 20,000 Hertz, which puts many natural vibrations outside of our hearing range. Our Earth generates audible and inaudible sounds from deep within the planet, down to background hums as deep as 10,000 times lower than the ear can hear.

High above, electromagnetic waves propagating through the inner region of Earth’s magnetosphere, called the plasmasphere, create their own type of music. In this space above our planet, waves such as whistler-mode waves, chorus waves, and plasmaspheric hiss waves are associated with everything from the tug of the Moon to lightning strikes. (Lightning also creates waves that have been seen to bounce and “ring” through the ionosphere.)

The plasma there is far too thin for its vibrations to be able to tickle our eardrums. But, as with the CMB, these electromagnetic waves can be recorded by antennas and converted into sound. For instance, lightning causes electrons to oscillate in waves that, when played through speakers, sound like whistles — hence the name whistler-mode waves. It’s worth noting that transforming such waves into audible sound is akin to the way visual astronomers collect light at frequencies our eyes can’t see — say, infrared light using the James Webb Space Telescope — and transform it into a visual image.

These waves are not unique to Earth. Voyager 1 first recorded whistler-mode waves associated with lightning in Jupiter’s plasmasphere in 1979. Now referred to as jovian whistlers, they provide proof of otherworldly lightning and share with us a small taste of sound from the largest planet in our solar system. Both Voyager spacecraft have also now passed through the heliopause — the boundary of our solar system where the solar wind collides with the surrounding interstellar plasma — and have recorded many types of oscillating plasma waves. Ironically, as we listen to interstellar space and the phenomena that shape it, from underlying galactic rotation to supernovae and smaller solar eruptions, the Voyagers carry a representative sample of Earth’s natural sounds and musical compositions in the form of the Golden Record produced by NASA and Carl Sagan.

Many stars oscillate in numerous ways as well, from hydrogen-burning main sequence stars like our Sun to pulsating variable stars to quaking neutron stars. Some oscillations are due to turbulent plasma trapped in stars’ upper layers; others come with changes brought on by age. Starquakes and pulsations can produce variations in a star’s brightness, and observations of these oscillations form the basis for the fields of helioseismology and asteroseismology. Such studies allow a further understanding of the inner structure and workings of stars at every stage

NASA’s A Universe of Sound project is an ongoing program to sonify astronomical image data taken at multiple wavelengths. Targets include the galactic center (top), the Cassiopeia A supernova remnant (lower left), and the Pillars of Creation (lower right). You can explore the available sonifications at https://chandra.cfa.harvard.edu/sound. NASA/CXC/SAO/K.ARCAND, SYSTEM SOUNDS (M. RUSSO, A. SANTAGUIDA)

SONIFICATION

Enriching the exploration between sound and space is the recent increased interest in sonification — the process of converting data into sound. While abstract for some, it creates a new world of imagery for blind or visually impaired individuals interested in or working in the sciences.

Sound engineers and astronomers are now collaborating to create a vocabulary using musical terms such as *timbre*, *tone*, and *pitch*, associating them with spatial imaging. Imagine an astronomical image as a field of complex data points containing information such as brightness and wavelength, which taken together can have a host of other visual descriptors often taken for granted by fully sighted people. Via sonification, these points become audio representations, allowing the visually impaired to experience the cosmos — and sighted individuals to experience visual and other information in an entirely new way. *—D.G.*

of their evolution. If we accept that the physics of sound Pythagoras discovered holds constant, then it is plausible that all these events produce pitches, overtones, and harmonics with frequencies that can be converted into the audible range.

Even catastrophic events can yield auditory treasure. A study published earlier this year in *Nature* revealed that some gamma-ray bursts (GRBs) contain more than just noise. GRBs that occur when two neutron stars collide can create short-lived hypermassive neutron stars (HMNS), the fastest spinning stars in the universe. They are difficult to study, lasting only seconds before collapsing into a black hole. In the paper, astronomers reported they were able to recognize the presence of an HMNS by the frequency at which the staccato blast of gamma rays flickered. The trick is that the oscillations of HMNSs lack a consistent pitch; instead, they produce a variety of so-called quasi-periodic oscillations around a peak frequency, adding clamor to our celestial orchestra.

What is music?

I imagine the future may hold similarly difficult-to-define patterns that will need more complex deciphering. In the meantime, the variety of identifiable signals we receive can be recorded, processed, resynthesized, and brought into the audible range. With varying rhythm and amplitude, some pitches and sounds rise and fall, while others remain constant. They can be reflective of lions roaring, a heart beating, or familiar ever-present white noise. More tonal results have been referred to as birds chirping or flocking, early video game sound effects, or ascending and descending vocal glissandos.

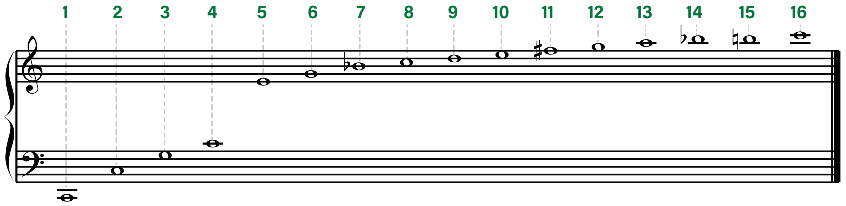
None of the samples we obtain from space may be music as most of society has come to define it. But is there a definitive definition of music? Today's contemporary music would probably be unidentifiable to the ears of the first singers of Gregorian chant. And consider “4′ 33″” by the celebrated 20th-century composer John Cage, who believed the three-movement composition his most important work. It is four minutes and 33 seconds in which the performer sits in silence — which provokes the question of whether any and every auditory experience can be regarded as musical.

Is it possible that the breathtaking sight of a globular cluster with exoplanets rotating around their suns also produces yet-to-be-captured sounds? Could galactic groups generate collective waves that create a unique cosmic symphony? Maybe this would be the true music of the spheres. Would we perceive what we hear as a cacophonous jungle filled with alien, unconnected sounds? To some, yes. But that same term — cacophony — has also been used to describe the sound created when multiple piano keys are simultaneously played as closely as possible. In composition, this is referred to as a cluster chord, which sounds like noise to many but is nonetheless 100 percent musical.

Twenty-four centuries after Pythagoras died, Danish composer Rued Langgaard wrote a groundbreaking orchestral homage in his “Music of the Spheres.” More than 100 years after that, the British rock band Coldplay released their *Music of the Spheres* album, with each track representing a celestial body. Clearly, the impact of this spiritual, philosophical, mathematical, metaphysical, scientific, and astronomical concept has resonated throughout the millennia. I, for one, am standing by to enjoy the ongoing evolution and wonderment of this sonic journey.

David Grossman *is a retired music executive and amateur astronomer who believes first contact is inevitable and hopes it will occur in his hometown of Santa Barbara, California.*

EXPLORING HARMONICS

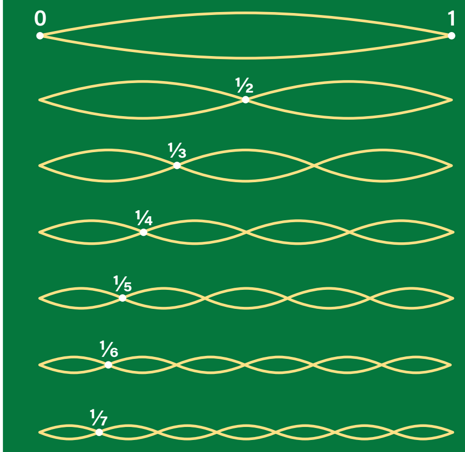


OVERTONES OF C

This notational representation shows the first 16 harmonics of the overtone series, using C as the fundamental, or root note. GUY MANOR

STILL HAVING TROUBLE IMAGINING THE OVERTONE SERIES? Try this: Take a moment with a piano in a quiet room. Find middle C and C an octave below it. Press down softly on middle C so the hammer does not strike the piano string. While keeping the key depressed, play the C an octave below as a short (staccato) note and listen carefully for the first overtone. Now try it with the next overtone (G), and so on, and you will hear the unmistakable additional harmonics to your C fundamental. *— D.G.*

THE OVERTONE SERIES



110 Hz Fundamental frequency/1st harmonic

220 Hz 2nd harmonic/1st overtone

330 Hz 3rd harmonic/2nd overtone

440 Hz 4th harmonic/3rd overtone

550 Hz 5th harmonic/4th overtone

660 Hz 6th harmonic/5th overtone

770 Hz 7th harmonic/6th overtone

This illustration shows how a string that is anchored at both ends (such as on a guitar) resonates when plucked. Not only does the entire string vibrate at the fundamental frequency, but also in halves, thirds, and so on, creating overtones. Here, the first seven harmonics are shown, based on A as the fundamental. *ASTRONOMY:* ROEN KELLY, AFTER WALK THAT BASS (WWW.THEJAZZPIANOSITE.COM)

Choosing a camera for eclipses

Here's what you need to capture award-winning photos. **BY MICHAEL E. BAKICH**

CAMERA: BEST BUY. ECLIPSE: ALEKSEY BASKAKOV/DREAMSTIME.COM

YOU MAY HAVE SEEN AN ECLIPSE OR TWO and are now motivated to become an astronomy hobbyist. The great April event is the perfect opportunity to start working on your astrophotography skills. But do you have the ideal camera for the task?

▲ If you follow our suggestions and treat yourself to a Canon DSLR, this is what the complete package should look like. Another advantage is that all Canon DSLRs can connect to a telescope with a manufacturer-specific T-ring and nosepiece.

The first option that may come to mind is the one included in your cellphone. Modern cellphone cameras are excellent for close-range images, but once you want to zoom in, the image becomes pixelated and loses its resolution. And even with a sharp image, any size beyond a phone background will destroy the clarity. Point-and-shoot or compact cameras are easy to use, but more often than not, they lack the ability to swap out lenses for different shots and connect to a telescope.

If you want a top-quality image of the April eclipse, the best options are either a digital single-lens reflex (DSLR) or mirrorless camera. Both vary in construction and price, but not in their sensors nor core features. Here's how to choose the right one, even on a budget.

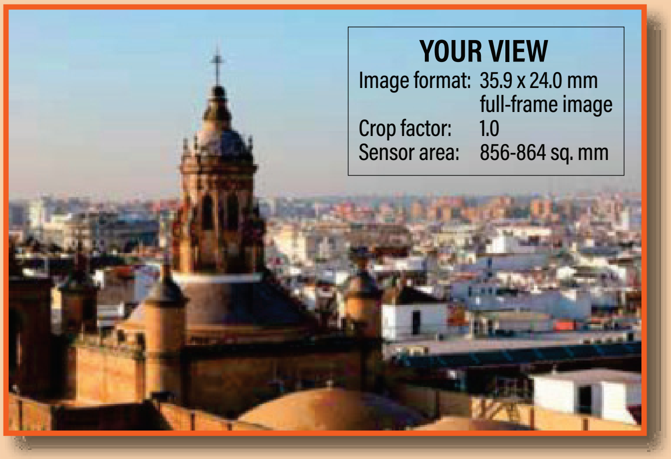
Choosing an image sensor

Not only do DSLRs and mirrorless cameras have larger sensors (or chips) than other cameras, they have two different chip options.

The first is a full-frame sensor. Professional photographers demand these because they capture a wider scene and collect more light than smaller sensors, producing a higher signal-to-noise ratio and improving the overall quality. Nighttime astrophotographers treasure this feature because it means they can shoot at high ISO numbers — which can lighten or

Full-frame body

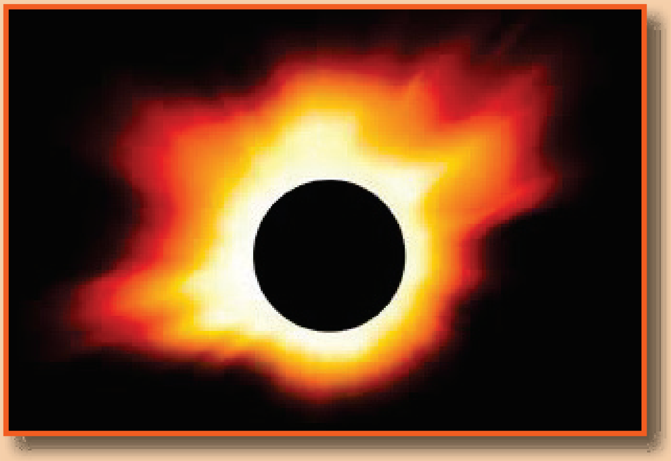
BEST BUY



YOUR VIEW

Image format: 35.9 x 24.0 mm full-frame image
Crop factor: 1.0
Sensor area: 856-864 sq. mm

This photo looking toward the Church of the Annunciation in Seville, Spain, was taken on a full-frame Canon EOS RP camera. CANON



The coronal streamers visible during an eclipse can fill plenty of space within your camera frame. A streamer's base can reach up to 1.5 solar radii, whereas the stem could extend several more. To capture the streamers from base to tip, a full-frame sensor is best. MAKSIM NIKALAYENKA

darken the image — without introducing noise to the image.

The second type of sensor is the Advanced Photo System type-C (APS-C) sensor, which has an image aspect ratio of 3:2. This chip measures 1 inch by 0.7 inch (25.1 millimeters by 16.7 millimeters). Compared to a full-frame chip, an APS-C sensor crops the image so the subject occupies more of the frame, resulting in a narrower view. The difference changes the effective focal ratio of a lens by a factor of around 1.6.

Another big difference is that full-frame models (and mirrorless cameras, in general) are more expensive. In the case of photographing eclipses, you'll be concentrating on the Sun, which is a ½°-wide circle of sky, plus the corona, which may extend 2° or 3° across. Spending $2,000 for a full-frame-chip camera is unnecessary when a $500 model will do.

A full-frame sensor will give you a wider, "zoomed-out" final image, versus an APS-C sensor that shows a narrower view of the scene you're photographing.

At the end of the day, cameras with APS-C sensors produce top-of-the-line images of eclipses, and may be best for both your budget and your broader use.

Megapixels: More isn't always better

Camera chips are covered with tiny light-collecting elements called pixels (the smallest units of a digital photo), arranged in rows and columns. Manufacturers measure a camera's resolution based on the number of megapixels, or MP, (each MP equals 1 million pixels) on its chip. If a certain camera's chip contains 4,000 rows and 3,000 columns of pixels, then it has a total of 12 MP (or 12,000,000 pixels).

It may be logical to think that a sensor with more MP will have higher resolution. However, this isn't always true because not all pixels are the same.

Pixels can come in different sizes. For instance, cellphone sensors are only a fraction of the size of a full-frame sensor. To pack millions of pixels onto cellphone sensors, manufacturers use much smaller pixels than those in DSLRs. As pixels become smaller, their ability to collect light decreases. The larger pixels used on DSLRs capture more light, produce better color, and have less noise.

Beauty is in the lens of the beholder

The camera lens is the vital key that determines the camera's true strength. If the lens is low quality, no amount of processing or editing will help.

A larger width means more light gets to the sensor. The focal ratio — also referred to as aperture setting or f/stop — of a lens determines how wide it can open. A smaller f/stop means the aperture can open wider. For example, an f/4 lens will produce a brighter image than an f/18 lens. Despite photographing the Sun, incoming light should still be considered. During totality, the strength of the Sun's light will be only one-millionth that of the full disk.

There's another critical aspect of focal length to consider on eclipse day: The larger

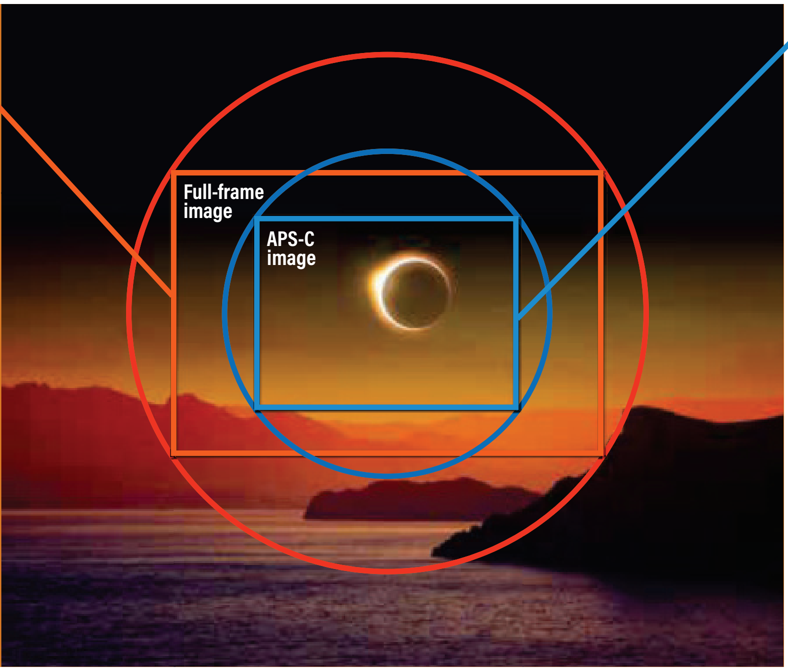


PHOTO: IGORZH/DREAMSTIME.COM

the number, the larger the Sun will appear in your photo. To figure out its size, you'll have to determine your camera/lens combination's field of view (FOV).

The equation you need is: FOV=2*arctan(0.5*s/f)*180/π. Don't let the equation intimidate you. To calculate your FOV, take the chip dimension (s) and divide it by the focal length (f) of the lens. Both s and f should be in millimeters. Next, divide that number by 2. Then, find the arctangent (or inverse tangent) of that number — this can easily be done with most smartphones or using Google's online calculator. Finally, multiply that number by 114.6 (the value of 2*180/π). Now you have your field of view expressed in degrees.

This formula is one-dimensional — in other words, it gives only x or y, the width or height of your chip. Thus, for a 2D FOV, you'll have to perform this calculation twice. If you're attaching your camera to a telescope, its the same equation. The scope's focal length is either on the tube or the ring that secures the front optic. If not, look in your instruction manual.

Eclipse considerations

I suggest finding a new mirrorless camera or a used Canon camera with an APS-C sensor. Set the sensor size to 12 MP as your minimum. Then select a lens that will give you the final Sun size that you'd want.

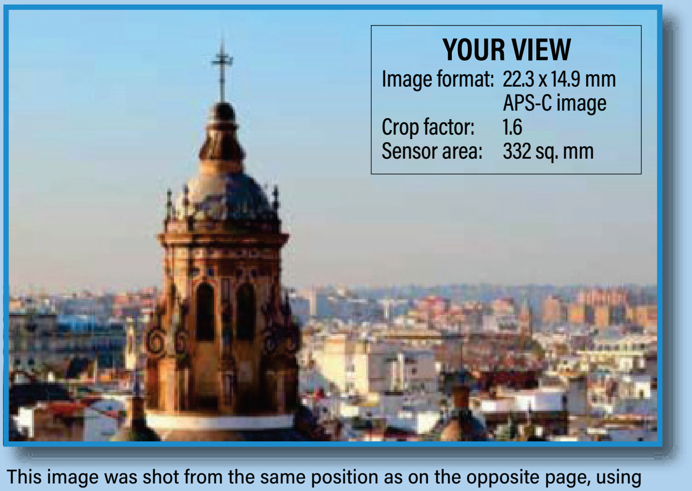
Always take the proper precautions to avoid eye or camera damage. And a bit of advice: Try focusing on the Moon while following the solar eclipse through its phases (the Sun might be too bright and too small).

When you get some images you're proud of, send them to photoeditor@astronomy.com. They just might appear online or in print.

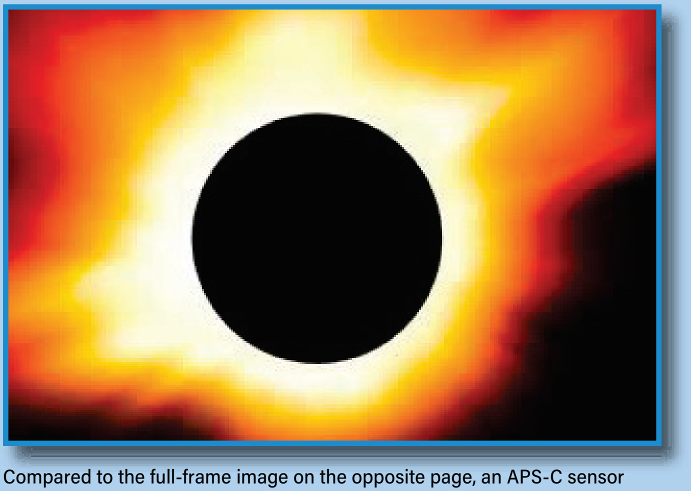
Michael E. Bakich *is a contributing editor of* Astronomy *who has seen 14 eclipses.*

APS-C body

BEST BUY



This image was shot from the same position as on the opposite page, using the same lens, focal length and settings, but with an APS-C camera. It was taken with a Canon EOS R10 camera. CANON



Compared to the full-frame image on the opposite page, an APS-C sensor produces a similar image, but zoomed in on the eclipse. This type of sensor is ideal to capture the more precious eclipse features — for example, solar prominences or Baily's beads. MAKSIM NIKALAYENKA

SKY THIS MONTH

Visible to the naked eye
Visible with binoculars
Visible with a telescope

THE SOLAR SYSTEM'S CHANGING LANDSCAPE AS IT APPEARS IN EARTH'S SKY.

BY MARTIN RATCLIFFE AND ALISTER LING

Winter nights offer excellent views of the solar system. Here, a setting Venus blazes low in the sky. ALAN DYER

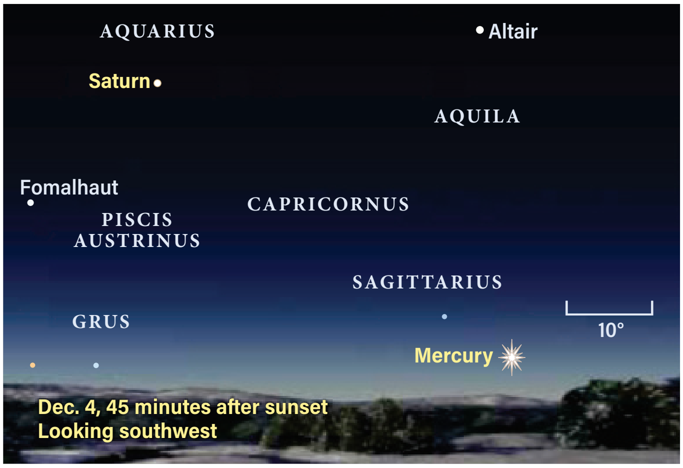
DECEMBER 2023

Giants still rule the night

Catch a glimpse of innermost planet Mercury soon after sunset in early December. Once darkness falls, you'll find Saturn descending in the south and Jupiter high in the east. Both are ideally located for easy telescopic views in the early evening. Jupiter is near its best for the year and you'll have many hours to watch its rotating cloud belts until well after midnight. Uranus and Neptune remain within reach of binoculars, while Venus lights up the morning sky, rising a few hours before dawn.

Mercury stands 6° high 30 minutes after sunset on Dec. 1. Shining at magnitude –0.4, you'll find it low in the southwest. It sets within another 40 minutes. This narrow window improves slightly by the 4th, when Mercury achieves its greatest eastern elongation from the Sun at 21° east of our star. It's gained nearly 1° of altitude 30 minutes after sunset, giving you an extra five minutes of observing time. A close-up view with a telescope reveals a 62-percent-lit gibbous disk on the 4th, which diminishes to just over 50 percent lit by the 7th.

Slowly sinking



Dec. 4, 45 minutes after sunset
Looking southwest

Mercury is visible for the first half of December, sharing the early-evening sky with Saturn and a scattering of bright stars. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

Mercury fades to magnitude 0 by Dec. 11, maintaining a similar altitude above the southwestern horizon, but after this date it drops quickly and dims further, down to magnitude 0.7 by the 15th. Soon after this, you'll lose sight of the small planet. Mercury reaches inferior conjunction on the 22nd.

Saturn is well placed high in the southern sky as twilight falls. Plan your viewing in the early evening, as it sets by 9 P.M. local time at the end of December. The ringed planet is located in southwest Aquarius about 20° above and to the west of Fomalhaut, the only 1st-magnitude star sitting lower in the southern sky. A beautiful five-day-old crescent Moon stands 3° south of Saturn on the 17th.

Saturn glows at magnitude 0.8 to 0.9 this month and is receding from Earth after its opposition in August. By mid-December, it lies

OBSERVING HIGHLIGHT

MERCURY reaches greatest elongation east of the Sun on Dec. 4.

10 astronomical units (930 million miles; 1 astronomical unit is the average Earth-Sun distance) from Earth. Through a telescope, its disk spans 16" and the major axis of the rings stretches 38" early in December, diminishing to 36" by the end of the month. The tilt of the rings to our line of sight drops to 9°, allowing clear views of most of the planetary disk.

Titan is the brightest of Saturn's moons. Spot it shining at magnitude 8.7 standing roughly north of the planet Dec. 12 and 28, and roughly south Dec. 4 and 20.

Tethys, Dione, and Rhea are also observable in small telescopes inside the orbit of Titan. All shine at 10th magnitude and constantly change position from night to night.

Tethys undergoes regular transits but with the narrow observing window, few are visible. One occurs early in the evening on Dec. 7th and again on the 24th. The following are approximate times; plan to be observing 15 to 20 minutes before the start. Tethys begins transiting at about 8:40 P.M. EST on the 7th and crosses for 90 minutes. On the 24th, the event begins around 8:27 P.M. EST and lasts about 108 minutes. It's difficult to see the moon visually because the bright disk of the planet hides it. The events are best recorded with high-speed

— *Continued on page 34*

RISING MOON | Dancing with perspective

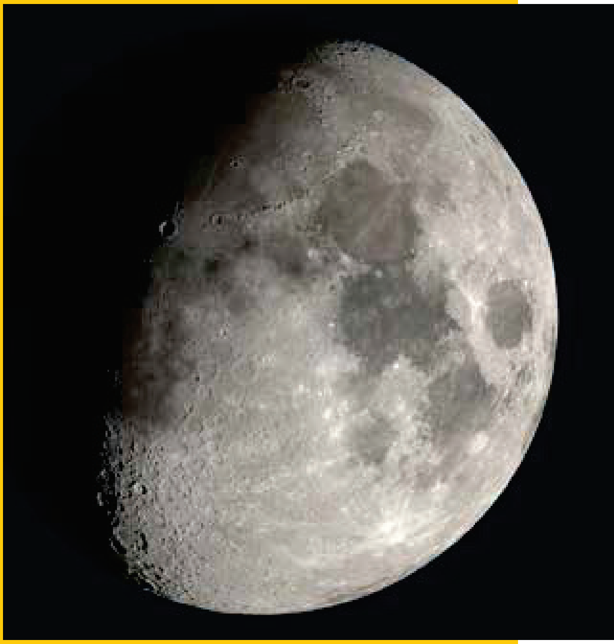
THERE'S MORE TO THE MOON than what's on it. Every month, our sister Luna performs a subtle sway for all of us to see — if we know what to look for. This month, let's concentrate on just one aspect of the movement: the dip and rise.

Turn the page to Paths of the Planets, where you can see the blue arc of the Moon swinging below and then rising above the red path of the Sun. This down-and-up motion is a result of the tilt of the Moon's orbit relative to Earth's. As the pair of us slowly twirl around the solar system's dance floor, Luna's head appears to rise and drop.

As a waxing crescent on the 16th, the Moon has dipped below us, the bright dimple of Furnerius tucked against the lower right of its face. With each passing day, Luna rises up and the dimple climbs away from the limb, and we see more under its "chin."

On the 21st, we're level eye to eye, when we can observe the first hints of the delicate tattoo of Mare Australis appearing at the southeast limb. The patchwork of darker markings is slowly revealed as the Moon becomes Full on the 26th. This southern sea is really part of a large farside basin partially filled with lava flows.

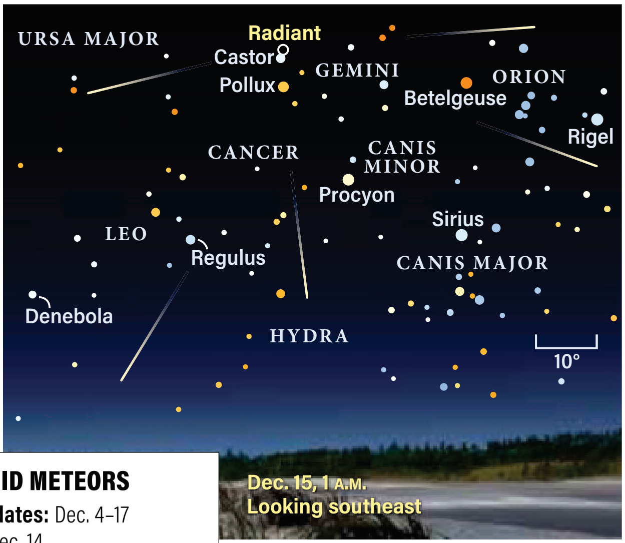
Luna has now reached the top of its move and slowly drops back down, but the change in the southeast now takes place in darkness, out of sight. Regular readers know I love the 3D shifting shadows near Mount Clementine at the south pole. Watch for these from the 24th to the 28th.



On Dec. 21, as the Moon waxes toward Full, we are viewing our satellite face-on with no tilt. NASA'S SCIENTIFIC VISUALIZATION STUDIO

METEOR WATCH | A sparkling show

Geminid meteor shower



Gemini is well above the horizon by 9 P.M. local time, and meteors can appear anywhere in the sky. Rates will increase through midnight.

GEMINID METEORS

Active dates: Dec. 4–17
Peak: Dec. 14
Moon at peak: Waxing crescent
Maximum rate at peak: 150 meteors/hour

A TWO-DAY-OLD MOON at the peak of the Geminid meteor shower makes this year's event very favorable, with dark skies all night. They're active from Dec. 4 to 17, peaking late on the 14th. The zenithal hourly rate, calculated for when the radiant is at the zenith, can reach over 100 meteors per hour. Soon after local midnight, with the radiant more than 65° high across the continental U.S., this results in peak rates above 50 meteors per hour, close to one per minute. This is as good as it gets for meteor watchers and is the best shower of the year. Settle back with warm clothes and a warm drink, and enjoy.

A second shower in December, the Ursids, peaks Dec. 22 just before midnight EST, but with far lower rates. It's active from Dec. 17 to 26 and on good nights can produce a meteor every five to 10 minutes.

STAR DOME

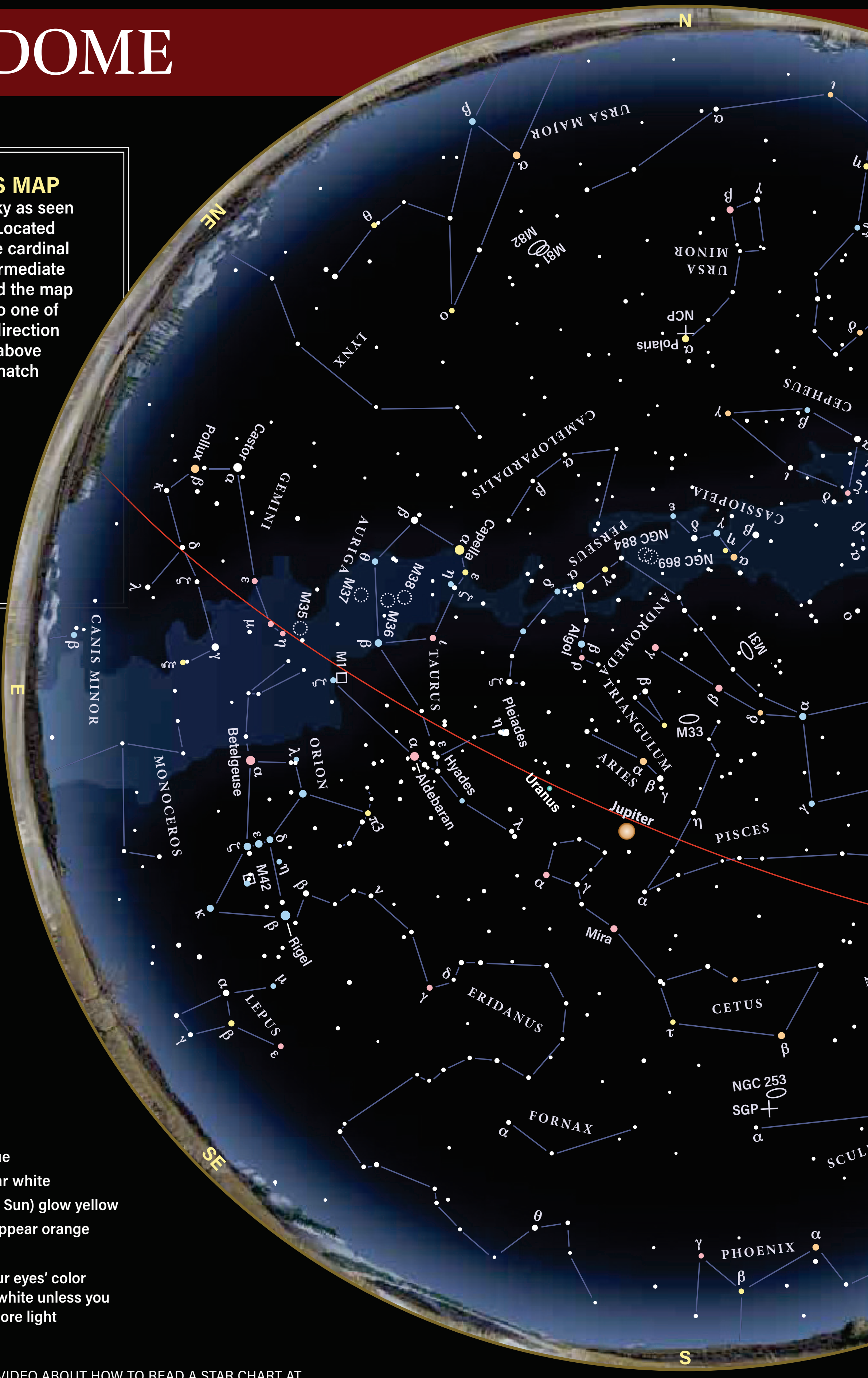
HOW TO USE THIS MAP

This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

9 P.M. December 1
8 P.M. December 15
7 P.M. December 31

Planets are shown at midmonth



MAP SYMBOLS

◌ Open cluster
⊕ Globular cluster
☐ Diffuse nebula
⌖ Planetary nebula
⬭ Galaxy

STAR MAGNITUDES

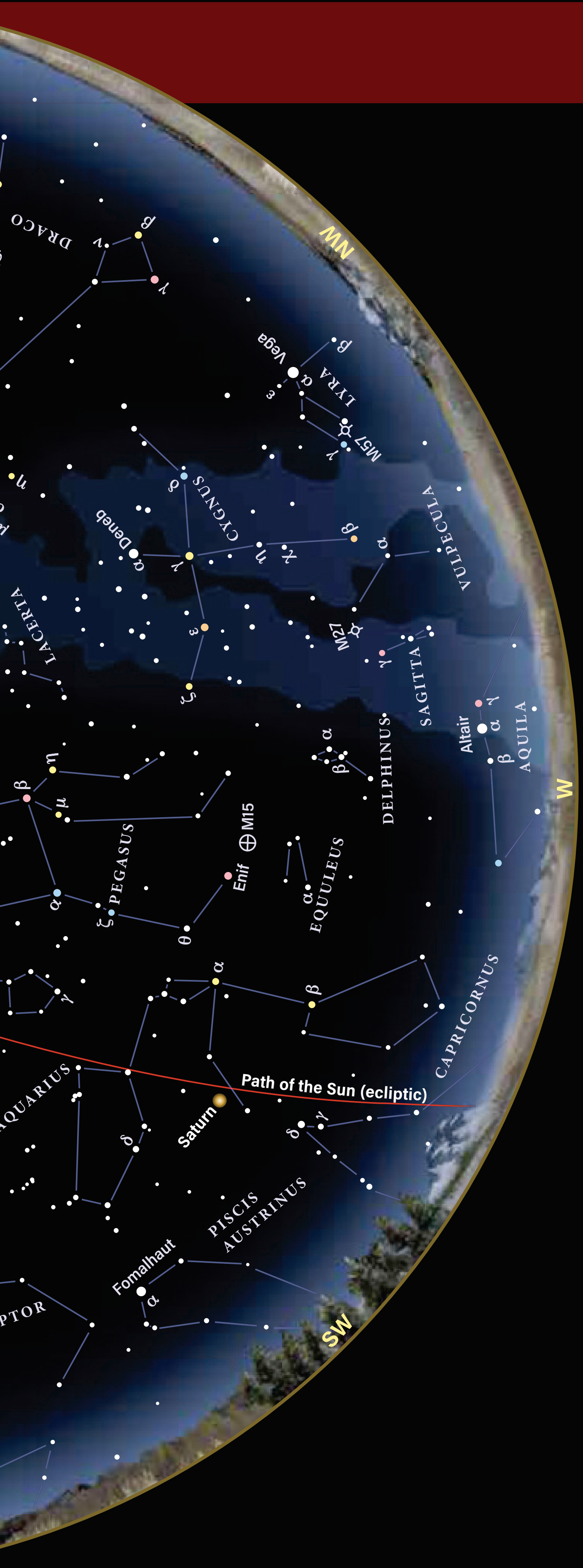
● Sirius
● 0.0
● 1.0
• 2.0
• 3.0
• 4.0
· 5.0

STAR COLORS

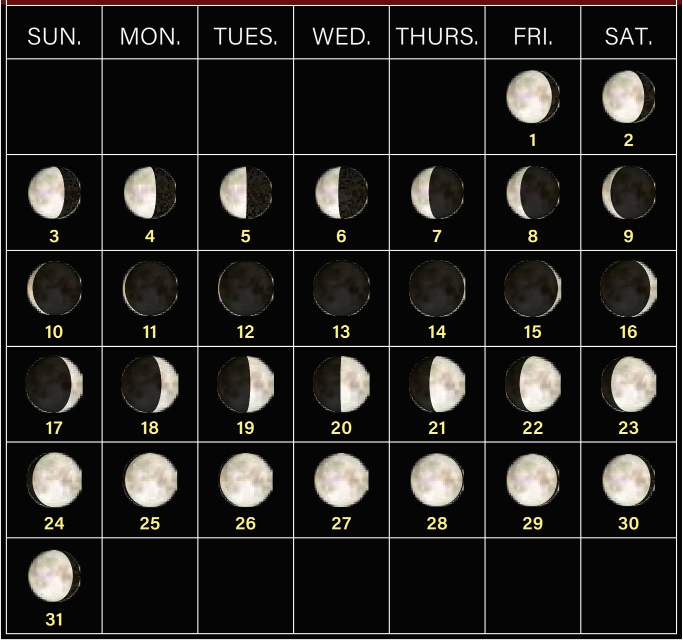
A star's color depends on its surface temperature.

- 🟦 The hottest stars shine blue
- ⬜ Slightly cooler stars appear white
- 🟨 Intermediate stars (like the Sun) glow yellow
- 🟧 Lower-temperature stars appear orange
- 🟥 The coolest stars glow red
- ⬜ Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**



DECEMBER 2023



SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

4 Mercury is at greatest eastern elongation (21°), 9 A.M. EST

The Moon is at apogee (251,249 miles from Earth), 1:42 P.M. EST

5 🌗 Last Quarter Moon occurs at 12:49 A.M. EST

6 Neptune is stationary, 7 P.M. EST

9 The Moon passes 4° south of Venus, noon EST

12 🌑 New Moon occurs at 6:32 P.M. EST

Mercury is stationary, midnight EST

13 The Moon passes 4° south of Mercury, midnight EST

14 Geminid meteor shower peaks

16 The Moon is at perigee (228,603 miles from Earth), 1:53 P.M. EST

17 The Moon passes 2° south of Saturn, 5 P.M. EST

19 The Moon passes 1.3° south of Neptune, 8 A.M. EST

🌓 First Quarter Moon occurs at 1:39 P.M. EST

21 Asteroid Vesta is at opposition, 2 P.M. EST

Winter solstice occurs at 10:27 P.M. EST

22 The Moon passes 3° north of Jupiter, 9 A.M. EST

Mercury is in inferior conjunction, 2 P.M. EST

Asteroid Metis is at opposition, 6 P.M. EST

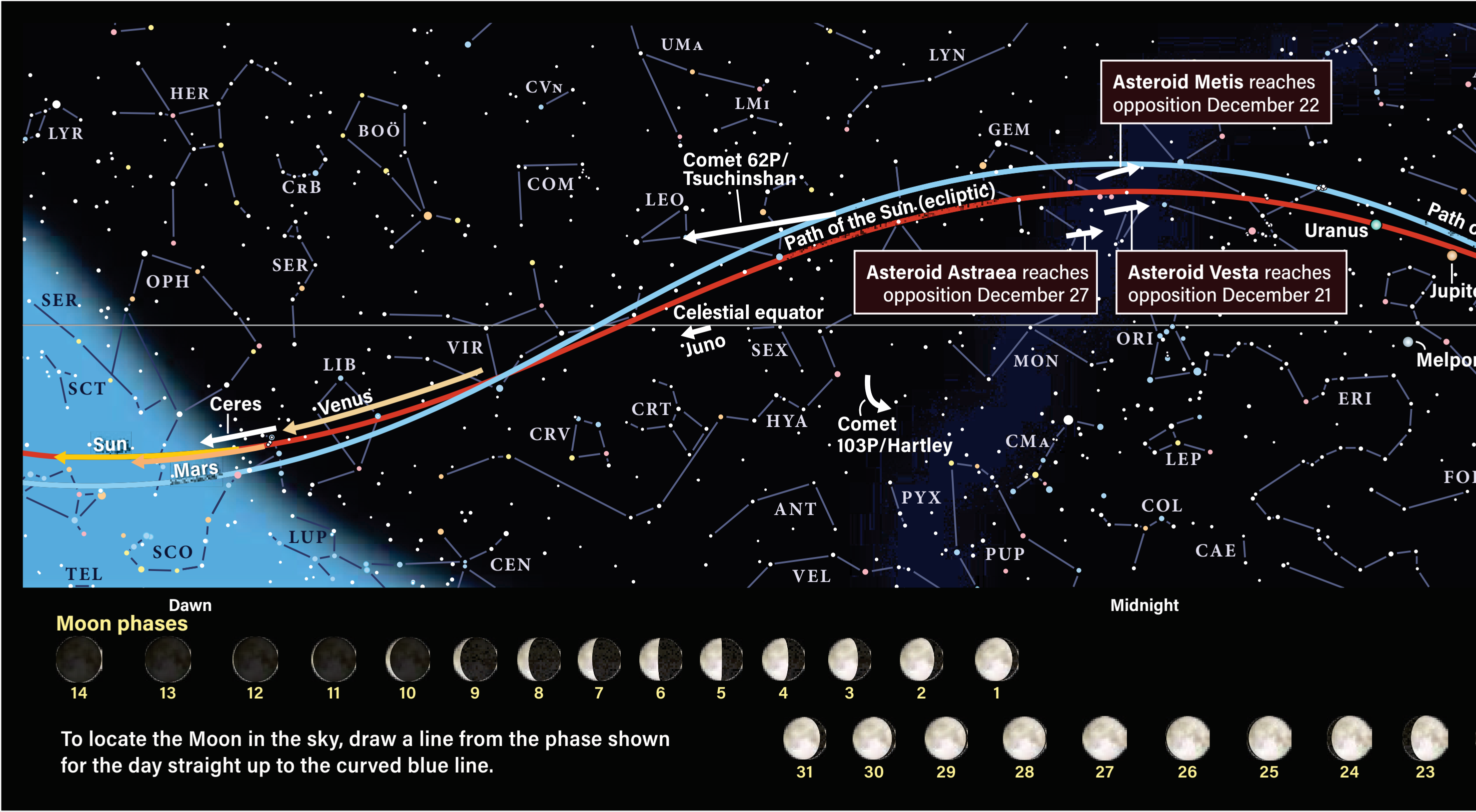
23 The Moon passes 3° north of Uranus, 10 A.M. EST

26 🌕 Full Moon occurs at 7:33 P.M. EST

27 Asteroid Astraea is at opposition, 5 P.M. EST

31 Jupiter is stationary, 10 A.M. EST

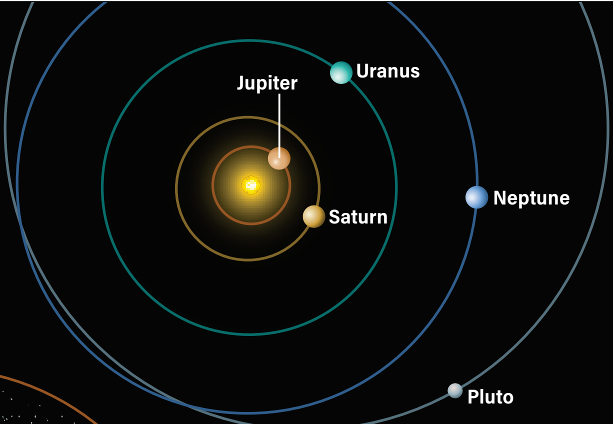
PATHS OF THE PLANETS

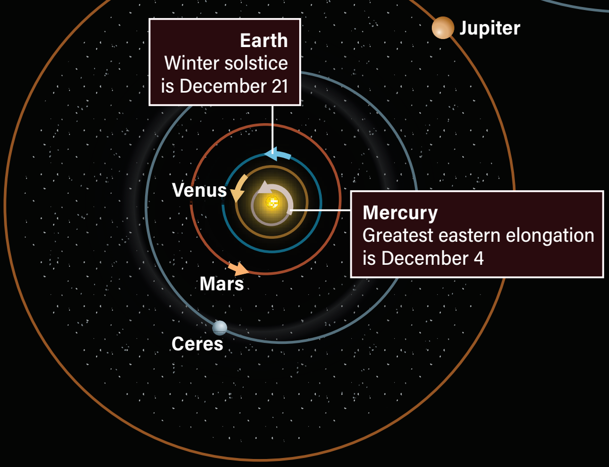


To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.

THE PLANETS IN THEIR ORBITS

Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at midmonth from high above their orbits.



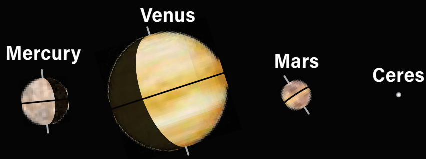


Earth
Winter solstice is December 21

Mercury
Greatest eastern elongation is December 4

THE PLANETS IN THE SKY

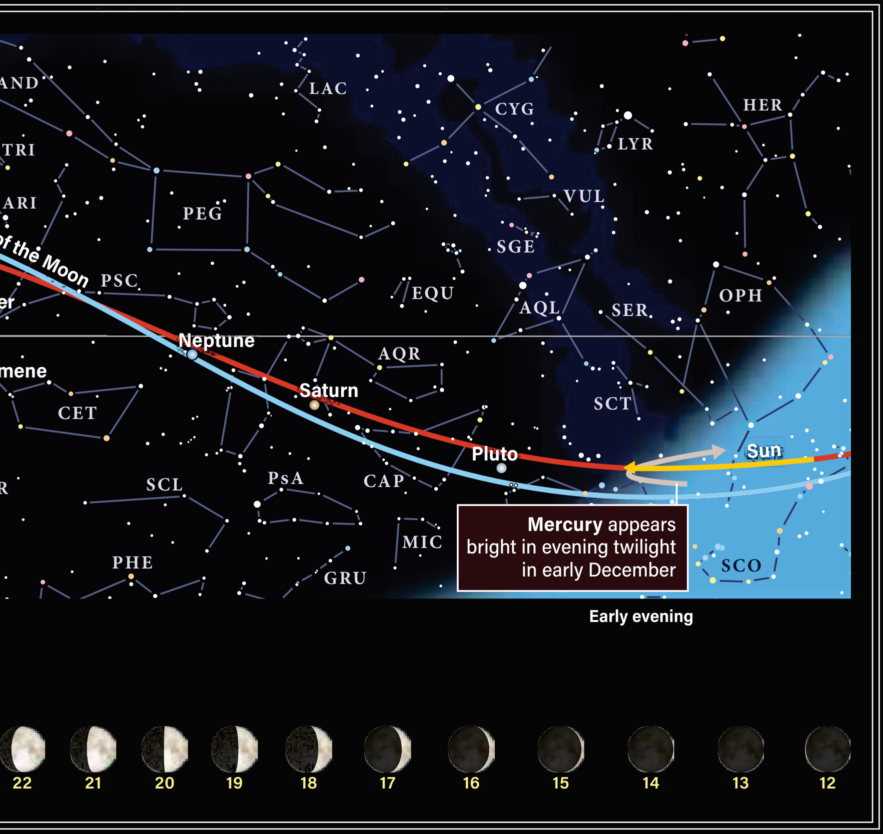
These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.



PLANETS	MERCURY	VENUS
Date	Dec. 1	Dec. 15
Magnitude	–0.4	–4.1
Angular size	6.2"	15.6"
Illumination	72%	73%
Distance (AU) from Earth	1.091	1.071
Distance (AU) from Sun	0.391	0.719
Right ascension (2000.0)	17h55.3m	14h40.2m
Declination (2000.0)	–25°51'	–13°13'

This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

DECEMBER 2023

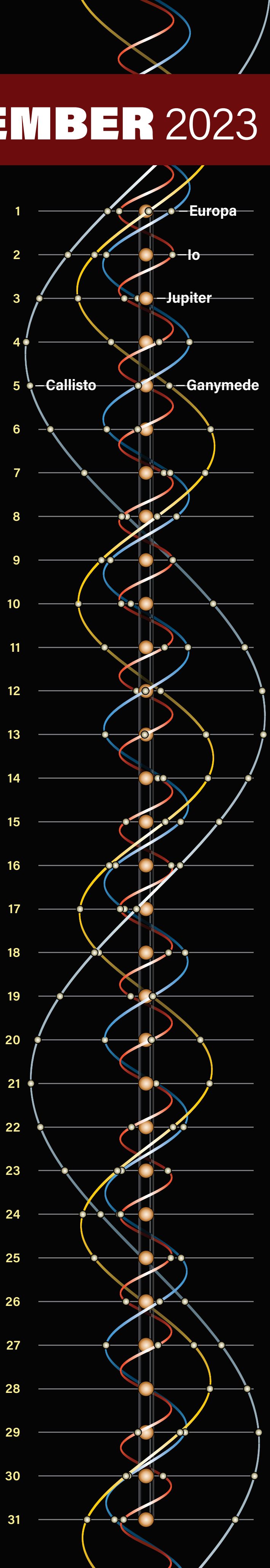


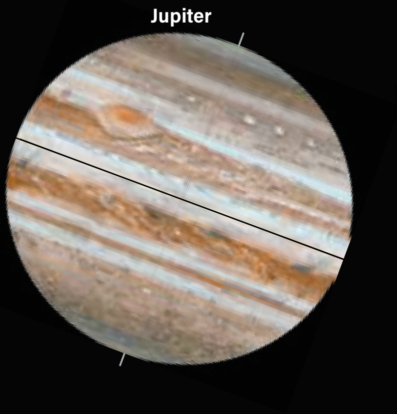
Mercury appears bright in evening twilight in early December

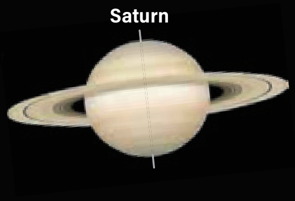
Early evening

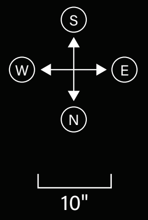
JUPITER'S MOONS

Dots display positions of Galilean satellites at 10 P.M. EST on the date shown. South is at the top to match the view through a telescope.







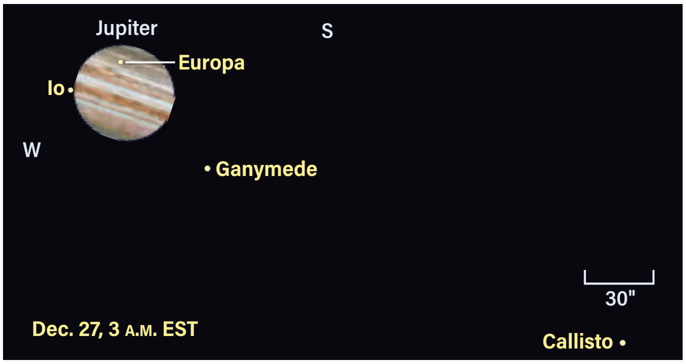


MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Dec. 15	Dec. 15	Dec. 15	Dec. 15	Dec. 15	Dec. 15	Dec. 15
1.4	8.9	–2.7	0.9	5.7	7.8	15.2
3.8"	0.4"	46.3"	16.5"	3.8"	2.3"	0.1"
100%	100%	99%	100%	100%	100%	100%
2.471	3.688	4.255	10.049	18.782	29.851	35.701
1.503	2.746	4.982	9.743	19.616	29.904	34.911
16h52.5m	16h26.8m	2h15.3m	22h16.8m	3h08.6m	23h42.1m	20h05.0m
–22°55'	–19°19'	12°13'	–12°27'	17°18'	–3°18'	–23°09'

SKY THIS MONTH

— *Continued from page 29*

The perfect moment



Look at the right moment on Dec. 26/27 (depending on your time zone), and you can catch all the Galilean moons, including Europa in transit. A short time later, Io slips behind Jupiter and Ganymede passes into the planet's shadow.

video cameras designed for planetary observation.

Iapetus is just past its brighter western elongation in late November and moves closer to Saturn from our perspective, reaching superior conjunction Dec. 18. On Dec. 2, a 9th-magnitude field star lies 6' west of Saturn and Iapetus stands 3' southwest of this star, aiding with identification of this faint moon, shining at magnitude 10.5. Follow it toward superior conjunction, when it stands 24" southeast of the planet's center.

Neptune is visible all evening, though it sinks very low in the west before midnight, so catch it early. It shines at magnitude 7.7 to 7.8, requiring binoculars to view it. Neptune lies on the border of northeast Aquarius and southwest Pisces, just south of the Circlet asterism in Pisces. You'll find it 5° due south of magnitude 4.5 Lambda (λ) Piscium, the southeasternmost star in the Circlet. Magnitude 5.5 20 Piscium lies about 1.5° east-northeast of the planet. A First Quarter Moon sits nearby on Dec. 18 and 19.

The planet lies some 29.9 AU (2.8 billion miles) from Earth, its tiny bluish disk spanning 2" at that distance. Neptune's retrograde motion ends in early December and it barely moves against the background stars all month.

Jupiter is visible nearly all night and continues its retrograde path through Aries the Ram. It fades slightly from magnitude –2.8 early in the month to magnitude –2.6 by the 31st. The planet is a spectacular object and is joined by a gibbous Moon Dec. 21 and 22.

Through a telescope, Jupiter's disk is readily visible, spanning 48" on Dec. 1 and shrinking to 44" by month's end. With Jupiter climbing higher in the sky than it has been since 2015 for northern observers, it garners a lot of attention. Any telescope shows Jupiter's pair of dark equatorial belts straddling the equator. The Great Red Spot makes regular appearances, along with more subtle detail visible with patient viewing. Watch for stable moments of air for the clearest views, which create random occasions when detail is breathtaking.

Adding to the spectacle, the four bright moons undergo transits and occultations. At opposition, transiting moons and their shadows nearly overlap, while afterward the moon leads its shadow. Now that we're a month-plus past opposition, moons are followed much later by their accompanying shadow.

Highlights to watch for this month include a series of Io transits on Dec. 6, 13, 20, and 27/28. On the 6th, the transit occurs early in the evening, with subsequent events beginning progressively later each

WHEN TO VIEW THE PLANETS

EVENING SKY
Mercury (southwest)
Jupiter (east)
Saturn (south)
Uranus (east)
Neptune (south)

MIDNIGHT
Jupiter (west)
Uranus (west)
Neptune (west)

MORNING SKY
Venus (southeast)

COMET SEARCH | Good, but better to come

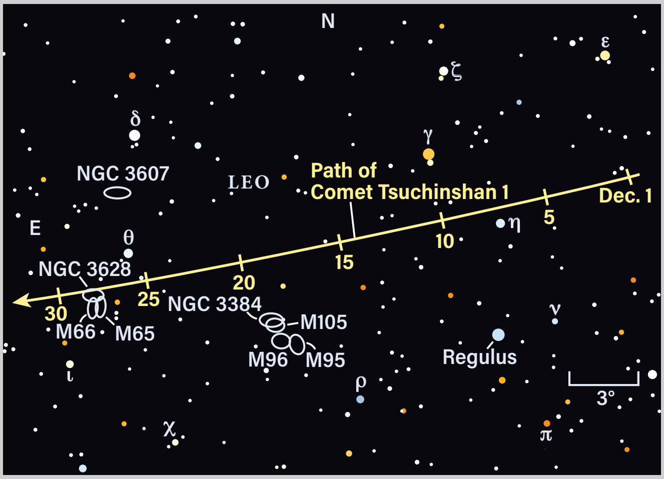
AN 8TH-MAGNITUDE COMET rivaling the brightness of many Messier galaxies is a welcome sight in any size scope under dark skies. Knuckle down and stay up until 1 A.M. for 62P/Tsuchinshan 1 to rise in the east above blue-white Regulus, the heart of Leo.

Discovered in 1965, Tsuchinshan 1 returns every 6.2 years to a spot 25 percent farther from the Sun than Earth. This time, it comes closest to the Sun Dec. 25th. Its size is unknown, but it can't be bigger than a mile because 7th magnitude is about as bright as it gets.

The dark-sky observing window opens on the 5th after midnight and before moonrise, and closes on the 17th as the waxing First Quarter Moon gets in the way. Imagers should shoot on the night of the 28th, when the greenish comet grazes the Leo Trio.

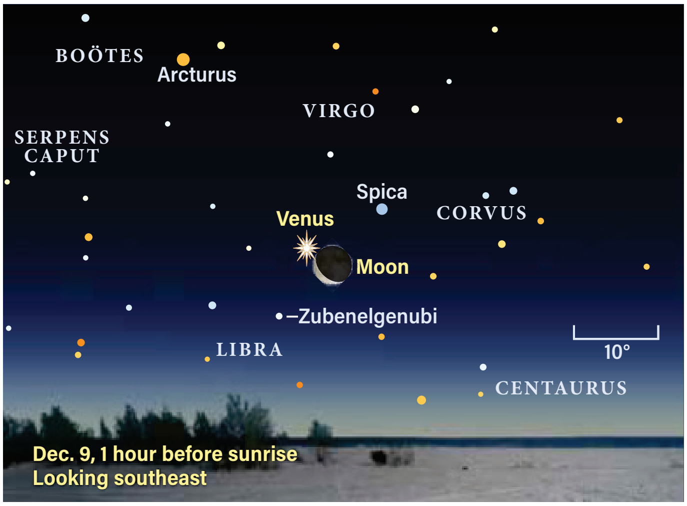
Itching for an evening comet? Try 12P/Pons-Brooks, now sliding past Vega. You'll want an 8-inch scope to pick up the small 10th-magnitude fuzz — unless it repeats its July outburst. Keep going and you can tag 144P/Kushida as it floats between Jupiter and Uranus in Aries.

Comet 62P/Tsuchinshan 1



Comet Tsuchinshan 1 crosses Leo during December, passing numerous popular deep-sky targets. This chart only shows galaxies magnitude 10 or brighter; Denebola lies just east of the left-hand boundary.

Bright light



Venus is an unmissable morning star rising several hours before the Sun. It shares the morning sky with the Moon early in the month.

time. Europa transits occur in a similar series on Dec. 5, 12, and 19, again transitioning from an early evening start to progressively later times.

Ganymede transits the southern polar region of Jupiter Dec. 1 starting at 10:19 P.M. EST and finishing at 11:45 P.M. EST. It repeats the transit Dec. 8/9, beginning at 1:42 A.M. EST (Dec. 9 in EST and CST, still the 8th in more western time zones) and ending 92 minutes later.

A pair of events occurs Dec. 26/27 as Europa approaches a transit late in the evening. Minutes after 12 A.M. EST on the 27th (the 26th in all other U.S. time zones), Ganymede reappears from behind Jupiter's northeastern limb — watch for 10 minutes as the growing brightness of the moon becomes apparent. The Europa transit begins about 90 minutes later, just before 12:30 A.M. CST on the 27th (again, still the 26th for the western U.S.). And less than two hours later, Ganymede disappears again, as the large moon goes into eclipse inside Jupiter's extended shadow.

Uranus is visible late into the night and is only a month past opposition. It stands roughly midway between Jupiter and the Pleiades star cluster (M45). Located about 9° southeast of M45 is a small group of stars shining between 4th and 6th magnitude. Delta (δ) Arietis is brightest, and a useful signpost to find Uranus. The bluish-green planet, glowing at magnitude 5.7, lies between 2° and 3° south-southwest of this star during December. Uranus travels westward as its retrograde path continues, carrying it farther from Delta. The planet stands 18.8 AU (1.75 billion miles) from Earth; through a telescope, it shows off a tiny 4"-wide disk.

Venus rises shortly before 4 A.M. local time with the stars of Virgo in early December, standing 4.5° northeast of Spica. As it approaches the border with Libra, you'll find a lovely 26-day-old crescent Moon some 4° south of Venus on Dec. 9. Two days later, Venus crosses into Libra, passing less than 2° north of Zubenelgenubi (Alpha [α] Librae) on the 17th. With Venus now at magnitude –4.1, it's a brilliant sight, with 1st-magnitude Arcturus in Boötes shining 35° above the planet in the sky.

Venus continues across Libra and ends the month just short of Scorpius. It stands 10.5° above Antares, the Scorpion's 1st-magnitude red giant, on Dec. 31.

Venus is receding from Earth. In a telescope, the disk shrinks from 17" to 14" during the month. The phase changes as well, growing from 68 percent lit on Dec. 1 to 78 percent lit by the 31st.

Mars is too close to the Sun to observe after its conjunction with our star last month.

Earth reaches its winter solstice Dec. 21 at 10:37 P.M. EST, when the Sun appears at its farthest south on the celestial sphere and begins its journey northward.

Martin Ratcliffe *is a planetarium professional with Evans & Sutherland and enjoys observing from Salt Lake City.* **Alister Ling**, *who lives in Edmonton, Alberta, is a longtime watcher of the skies.*

LOCATING ASTEROIDS

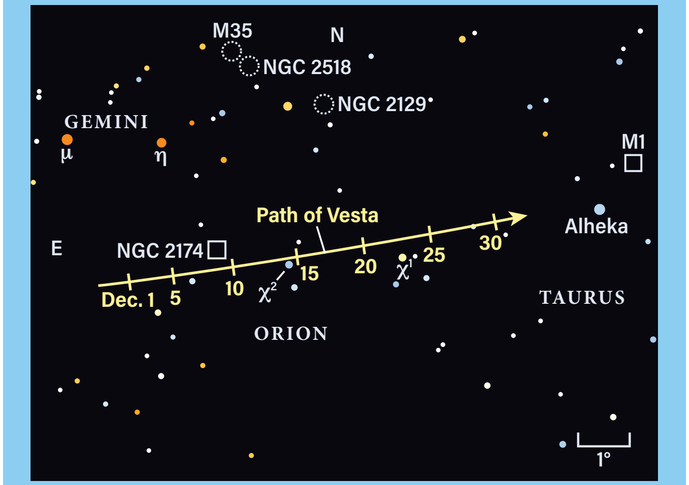
Dash out for a quick catch

EASY ASTEROID TRACKING has returned with 4 Vesta hitting magnitude 6.4 on the 19th. From the suburbs with scarcely any dark adaptation, you can walk outside, point your binoculars at the feet of Gemini, shift half a field to the right, and spot the fourth- or fifth-brightest object. Even if it is cracking cold, it won't take more than five minutes!

Copy our star chart or trace out the pattern of the brighter stars in a logbook, then each night you try, place a dot where you see Vesta. On the 7th, it lies just north of a brighter field star; it is tucked close to Chi^2 (χ^2) Orionis on the 14th and 15th. With any small scope at 80x, we can notice the space rock move over the course of three hours on the 29th as its position between two field stars shifts.

As the second-largest asteroid in the main belt, potato-shaped Vesta measures 330 miles across. Its reflectivity of 40 percent is four times that of our Moon, but half that of fresh snow.

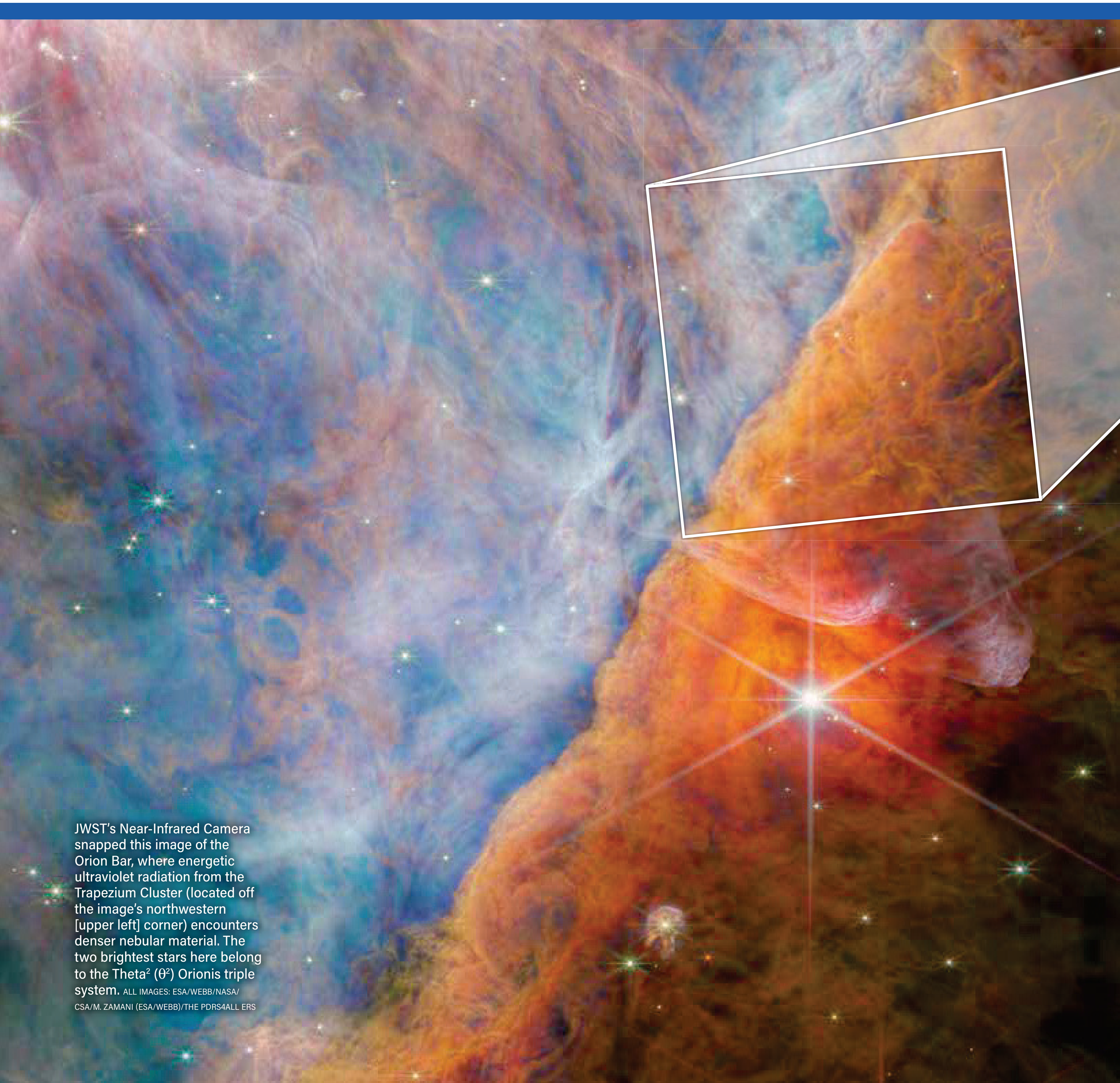
Easy pickings



Bright Vesta is sliding through far northern Orion, passing south of a few easy-to-nab clusters in Gemini.

GET DAILY UPDATES ON YOUR NIGHT SKY AT
www.Astronomy.com/skythisweek.

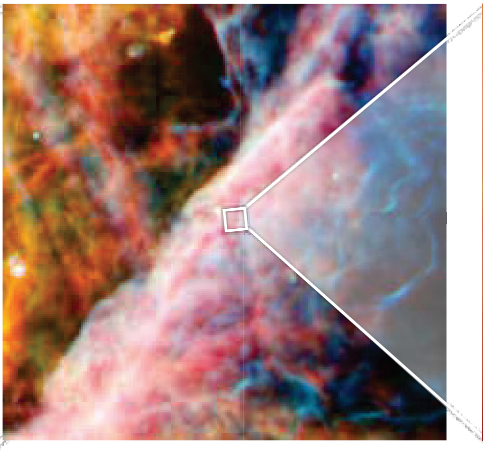
HUNTING FOR THE SEEDS



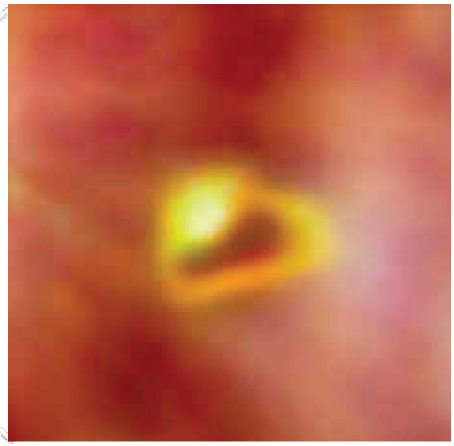
JWST's Near-Infrared Camera snapped this image of the Orion Bar, where energetic ultraviolet radiation from the Trapezium Cluster (located off the image's northwestern [upper left] corner) encounters denser nebular material. The two brightest stars here belong to the Theta^2 (θ^2) Orionis triple system. ALL IMAGES: ESA/WEBB/NASA/CSA/M. ZAMANI (ESA/WEBB)/THE PDRS4ALL ERS

For the first time, astronomers detect a carbon molecule in space that could play a critical role in the origin of life. **BY RICHARD TALCOTT**

OF LIFE



JWST's Mid-Infrared Instrument captured this close-up of the Orion Bar.



The protoplanetary disk d203-506 sits front and center. JWST discovered the methyl cation — molecules scientists view as vital for interstellar organic chemistry and the beginnings of life — in this disk.

SCIENTISTS SUSPECT OUR SOLAR SYSTEM formed some 4.6 billion years ago in a vast stellar nursery that ultimately gave birth to a few thousand stars. Today, our part of the galaxy holds only one comparable region: the Orion Nebula (M42). This spectacular deep-sky object lies just 1,350 light-years from Earth and provides astronomers with a ringside seat for exploring stellar birth.

The James Webb Space Telescope (JWST) recently discovered another startling similarity between our solar system and the Orion Nebula: They are the only two places in the cosmos known to harbor a molecule that likely plays a key role in interstellar organic chemistry and the genesis of life. The methyl cation (CH_3^+) turned up in observations of a protoplanetary disk surrounding a star cataloged as d203-506. (A cation is an atom or molecule with a net positive charge because it suffers a deficit of one or more electrons.)

Scientists began speculating in the 1970s that CH_3^+ could help create the more complex organic molecules that form the basis for life as we know it. The methyl cation makes a near-perfect facilitator for forming complex organic (carbon-based) compounds because it reacts easily with a wide range of other molecules, even in the frigid conditions of interstellar space.

Using JWST's unprecedented sensitivity and resolution, scientists studying d203-506's disk detected a series of emission lines that correspond precisely to the unique spectral signature of the methyl cation. Although astronomers traditionally identify molecules through their radio emissions, CH_3^+ emits only at infrared wavelengths that Earth's atmosphere absorbs, so the space observatory proved crucial.

The star is a dim red dwarf with a mass one-tenth that of the Sun that only recently began fusing hydrogen into helium in its core. It lies near the heart of the Orion Nebula, just a stone's throw from the massive 5th-magnitude star Theta^2 (θ^2) Orionis A, which itself lies barely 2 arcminutes southeast of the Trapezium Cluster that energizes the entire nebula.

Ultraviolet light pours from the cluster's hot, massive stars, ionizing the nebula's hydrogen gas and causing it to glow with a distinctive reddish hue. This powerful radiation also tends to destroy complex molecules, raising the question of how the methyl cation survives. The international team of scientists that made the observations suspects that ultraviolet light actually supplies the energy CH_3^+ needs to form while simultaneously breaking apart any water molecules nearby. This could explain why no traces of water were found around d203-506.

JWST's observations of other protoplanetary disks located farther from sources of intense ultraviolet radiation reveal lots of water. "[Our study] clearly shows that ultraviolet radiation can completely change the chemistry of a protoplanetary disk," said team leader Olivier Berné in a press release. The CNRS, CNES, and University of Toulouse researcher added, "It might actually play a critical role in the early chemical stages of the origins of life by helping to produce CH_3^+."

Intriguingly, meteorites that date to the origin of our solar system also show evidence that the material that ultimately formed the Sun and planets was bathed in ultraviolet radiation from a nearby massive star. Because such behemoths live for only a few million years, it has long since disappeared from our neighborhood.

Perhaps the same fate awaits the protoplanetary disk surrounding d203-506. And maybe one day, millions or billions of years from now, life will take root on a planet orbiting this dim red star.

Contributing Editor ***Richard Talcott*** *wrote about the 60th anniversary of quasars as well as JWST's observations of Fomalhaut in the November issue.*

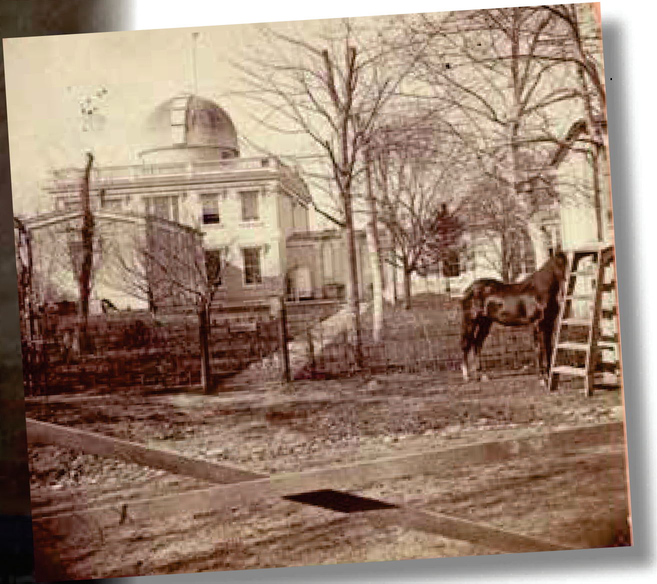
A DARK WAR

AND A BRIGHT NIGHT SKY

From great leaders to great comets, astronomy played a crucial role in the American Civil War. **BY DAVID J. EICHER**

LEFT: Frederic Church's painting of an aurora is reminiscent of the descriptions of an auroral show noted after the Battle of Fredericksburg in Virginia in 1862. SMITHSONIAN INSTITUTION

BELOW: The Old Naval Observatory building appears with a lone horse in this stereo image taken circa 1867–1869, just a few years after Lincoln's visit. The site stands several blocks north of the present-day Lincoln Memorial. LIBRARY OF CONGRESS



IN THE SUMMER OF 1863, the U.S. was in the middle of its greatest-ever crisis. A bloody civil war between the Southern Confederacy and the federal government had created hundreds of thousands of casualties, and to many, no end appeared to be in sight. By July of that year, however, things finally seemed to be brightening slightly for the hopes of a united country. Decisive victories for the Union at Gettysburg and Vicksburg gave the first glimmers of foresight that the war would eventually cease and that healing would begin.

Seven weeks after the Battle of Gettysburg, the nation's leader, Abraham Lincoln, paid an unusual Washington, D.C., visit. Accompanied by his young private secretary John Hay, Lincoln made an unannounced journey to the U.S. Naval Observatory to indulge his interest in astronomy and to seek a brief reprieve from the war. In those days, the observatory was located at 23rd and E streets, about three blocks north of what is now the Lincoln Memorial site. (This area, called Foggy Bottom due to the frequent haze and fog that rolled off the Potomac, wasn't the best site for a telescope, and eventually the observatory would move.)

On the night of Aug. 22, 1863, the observatory was manned by a young astronomer, Asaph Hall. Fourteen years later, Hall would discover the two moons of Mars, but on that evening, he was an unknown 33-year-old researcher. Lincoln and Hay arrived and introduced themselves — as if Lincoln needed to be introduced. The group climbed up a wooden ladder to the dome where the observatory's 9.6-inch refractor was located. There they observed the Moon and the star Arcturus.

In the 1980s, I was privileged to visit the historic site of the Old Naval Observatory, courtesy of Jan Herman, the observatory's former historian and a contributor to *Astronomy.* Climbing up the same wooden steps Lincoln had used to enter the dome gave me an ethereal feeling of the past, the present, and the universe, all meeting at one point.

Omens of victory and defeat

Not all participants of the Civil War sought to contemplate the meaning of the cosmos as Abraham Lincoln did, but some viewed certain events as a beacon of hope — or demise.

On May 13, 1861, an observer in New South Wales, Australia, found what came to be called the Great Comet of 1861. By midsummer, the comet had moved so that it was visible in the Northern Hemisphere sky and, according to astronomer Horace Tuttle, sported a tail 106° long.

The comet caused a press sensation. The evening spectacle came to be called The War Comet, and the editors of the *Brooklyn Daily Eagle* posed a question to their readers: "What means this visit — peace or war?" *Vanity Fair* published a cartoon showing Lt. Gen. Winfield Scott, the senior general of the Union army, as the comet's head and a slew of bayonets comprising the tail.

During this time, Charles Johnson, a private in the 9th New York Infantry, wrote in his diary, "The comet is now tired of his visit to these regions of space, or disgusted it may be with the appearance of things on this side of the planet, for he is now leaving in seemingly greater haste than he came, with his tail between his legs, for the unknown regions out yonder."

The Great Comet of 1861 faded during the week of the First Battle of Bull Run, leading to vast speculation on that meaning. But comets were not done with the war. In 1862, Tuttle discovered another comet that would rise to significant brightness. Astronomer Lewis Swift had also spotted the comet,

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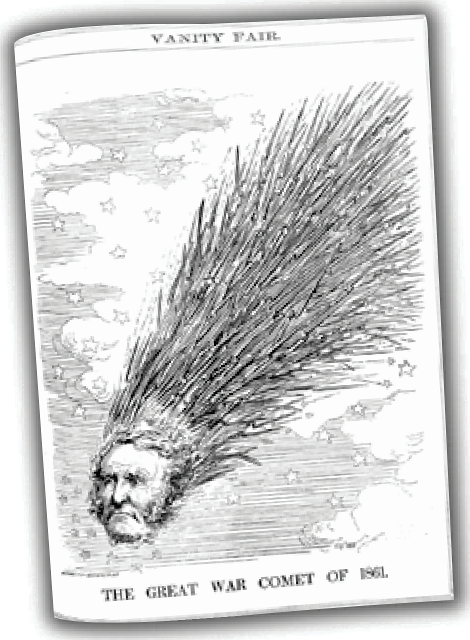

VANITY FAIR
THE GREAT WAR COMET OF 1861.

ABOVE: In August 1861, *Vanity Fair* published this satirical cartoon of Union General Winfield Scott as the Great Comet of 1861, with bayonets as the tail. THE BRITISH LIBRARY

RIGHT: This drawing of the Great Comet of 1861, also known as C/1861 J1 or Comet Tebbutt, appeared in the 1888 book *Picture Atlas of the Star World*. E. WEISS

which became known as Swift-Tuttle. When that comet faded in September 1862, many attached its significance — one way or another — to the battle of Antietam, a substantial Union victory. Decades later, astronomers would identify this comet as the source of the Perseid meteor shower.

In December 1862, during the battle of Fredericksburg in Virginia, a different kind of celestial omen made its appearance. After a slow and discouraging lack of progress during the war's first two years, Lincoln assigned Maj. Gen. Ambrose Burnside to command the Army of the Potomac, the principal Union army in the east. Burnside faced Confederate Gen. Robert E. Lee at Fredericksburg and sent repeated frontal attacks into the Rebel works, ending in a Union disaster.

Following the battle, as the cries of wounded filled the icy December air, an aurora appeared in the sky, visible to many thousands of soldiers on both sides. "A brilliant aurora illuminated the night and much facilitated the work upon the entrenchments," wrote Confederate Col. Edward Porter Alexander.

The light show was taken as an omen of victory by Southerners, who had inflicted heavy losses on the Yankee troops. And, of course, many Union soldiers saw it as an omen of doom. Citizens in Fredericksburg, in Charlottesville, and all over the region remarked on the unusual aurora. "Oh, child, it was a terrible omen," wrote Elizabeth Lyle Saxon in her 1905 reminiscences, quoting an elderly woman's words to her. "Such lights never burn, save for kings' and heroes' deaths." A writer for the *Richmond Daily Dispatch* proposed the crimson columns of light represented "the blood of those martyrs who had offered their lives as a sacrifice to their native land."

By the light of the Moon

In the following months, a significant event rocked the command structure of the Confederate Army. The battle of Chancellorsville in May 1863 was yet another huge win for the Confederacy, following the triumph at Fredericksburg. But in the action, the Southern general Thomas J. "Stonewall" Jackson, was accidentally and mortally wounded by other Confederate troops.

Recently, astronomers have shed some light — or rather some moonlight — onto why the events of that night led to Jackson's death. As the Sun faded on that fateful day at Chancellorsville, Jackson pressed his men forward. Stonewall's flank attack crushed a portion of the Union force, held by

LEFT TO RIGHT: On Aug. 9, 1862, Abraham Lincoln posed for this portrait in Alexander Gardner's Washington studio. Two weeks later he made a surprise nighttime visit to the U.S. Naval Observatory. LIBRARY OF CONGRESS

Maj. Gen. Ormsby Mitchel oversaw a famous episode of the Civil War, the Great Locomotive Chase through northern Georgia. Before the war, he established the Cincinnati Observatory. LIBRARY OF CONGRESS

At the battle of Chancellorsville, Lt. Gen. Thomas J. "Stonewall" Jackson was accidentally fired on and mortally wounded by his own troops in the moonlight. NATIONAL ARCHIVES AND RECORDS ADMINISTRATION

Maj. Gen. Oliver Howard's 11th Corps. Jackson rode out under moonlight to the Plank Road, assessing the situation and determining the feasibility of a night attack by the light of the Full Moon. Soldiers in the 18th North Carolina Infantry believed the small group of riders, including Jackson, were Union cavalry and opened fire. Jackson was hit with three bullets, including in his left arm, which had to be amputated later that night. Confederate doctors attempted to transport him to Richmond for follow-up care, but he developed pneumonia and died eight days later.

In 2013, a group led by Don Olson of Texas State University determined that, based on astronomical research and battle maps, Stonewall and his party would have been viewed as a group of dark silhouettes using the light of the Moon, which sat at a low 25° above the horizon, as their guide. Their positions ultimately obscured their identities, resulting in the soldiers mistakenly opening fire.

The astronomer general

North of the Mason-Dixon Line, another prominent figure was strongly associated with the night sky.

On the Union side, a well-known astronomer became one of the most prominent general officers in the western theater. Ormsby Mitchel had been born in Kentucky but grew up in Lebanon, Ohio, and was a classmate of Robert E. Lee at West Point. During his career, he helped establish the U.S. Naval Observatory and the Harvard College Observatory. Mitchel also studied the double star Nu (ν) Scorpii and found in 1846 that the fainter of the two stars was also a close double.

After West Point, Mitchel became a professor of mathematics at the military academy, but then returned to Ohio, became a lawyer and engineer, and began a professorship at Cincinnati College. He organized the Cincinnati Astronomical Society and became an early popularizer of the subject. In 1859, Mitchel moved to the Dudley Observatory in New York. But in 1861, as the war rapidly approached, he returned to his military roots at the age of 51.

Commissioned a brigadier general, Mitchel first supervised defenses around Cincinnati and Northern Kentucky. In 1862, he conspired with a Union spy, James J. Andrews, on a plot that would come to be known as the Great Locomotive Chase. Given the nickname Andrews' Raiders, they stole the Confederate locomotive *The General* in northern Georgia, intent on disrupting the important railway between Atlanta and Chattanooga. The plan that Mitchel ordered but did not participate in eventually failed. Many of the raiders were captured and eight were hanged by the Confederacy, including Andrews himself, while others were able to escape. Afterward, 19 of the living and executed men became the first recipients of the Medal of Honor.

Despite the raid's failure, Mitchel continued to lead other successful operations throughout the year. By September 1862, he was assigned command of a post in Beaufort, South Carolina, but he contracted yellow fever and died there in October.

A time of discovery

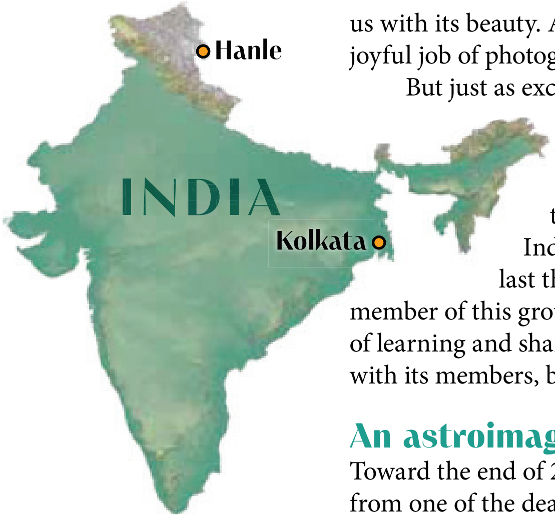
The era in which Mitchel lived and the Civil War occurred not only saw a dramatic upheaval of the U.S. but also witnessed the rise of astrophysics. During this time, a field of simple observing and cataloging transformed into understanding the physical nature of what the universe contains.

Out of a maelstrom of chaos eventually came order, a start down the long road to justice and equality, and the beginnings of an understanding of our larger universe.

David J. Eicher *is editor of* Astronomy, *author of 17 books on science, and author of nine books on the American Civil War.*

Astronomads Imaging in

India is home to one of the world's fastest growing astroimaging communities, and this group is at the movement's leading edge. **BY SOUMYADEEP MUKHERJEE**



THE SKY NEVER FAILS TO AMAZE us with its beauty. An astrophotographer has the joyful job of photographing and documenting it. But just as exciting is what comes next: sharing this beauty with others.

Astronomads Bangla, a group of amateur astrophotographers based in Kolkata, India, has been doing both for the last three years. And as a founding member of this group, I have experienced the joy of learning and sharing astrophotography not just with its members, but also the people of India.

An astroimaging journey

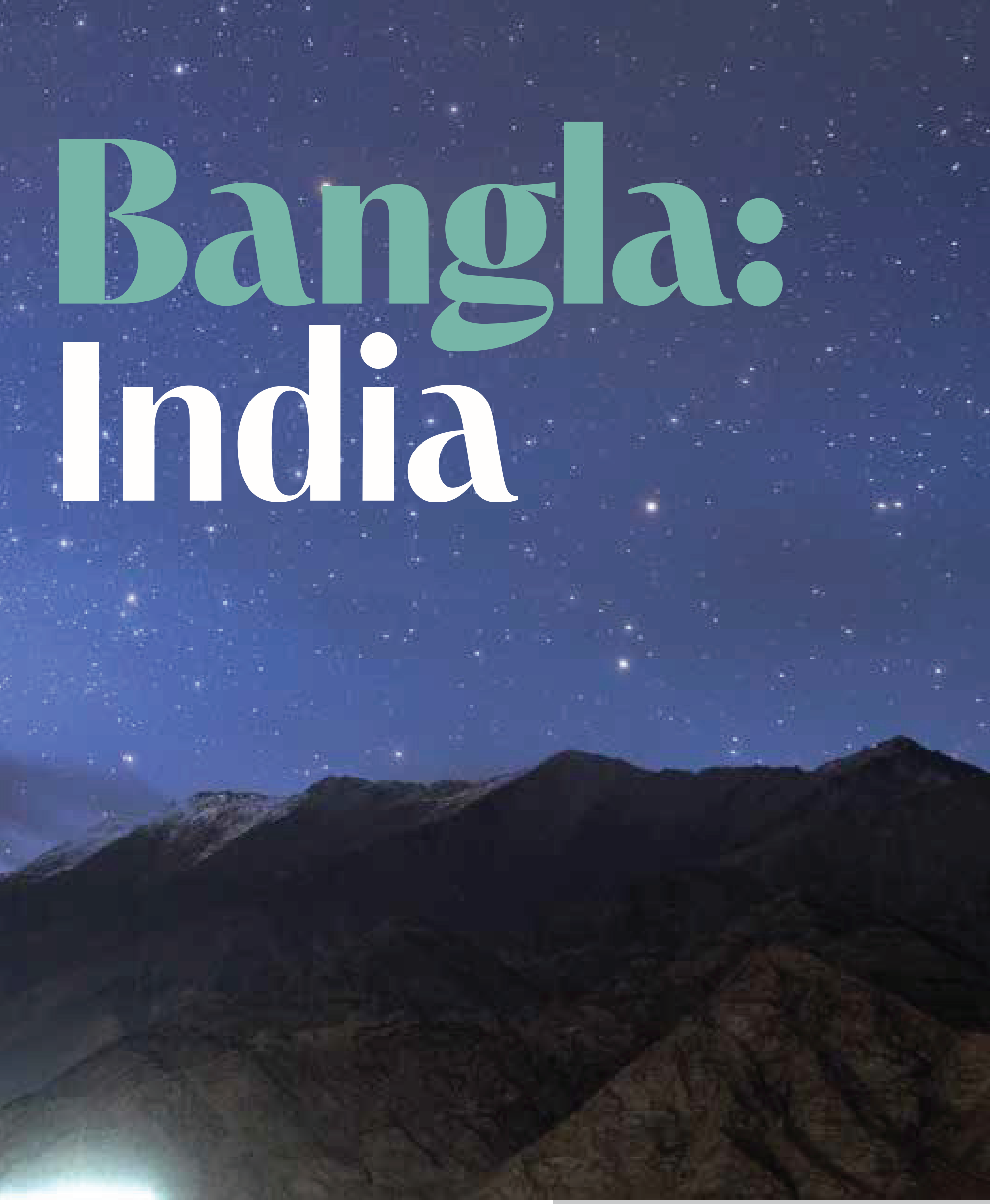
Toward the end of 2020, the world was suffering from one of the deadliest plagues that the modern age has ever experienced: the COVID-19 pandemic. Along with physical health concerns, for many, mental health was also suffering. People were fighting with the disruption of their daily routines. Everyone needed some sort of relief valve.

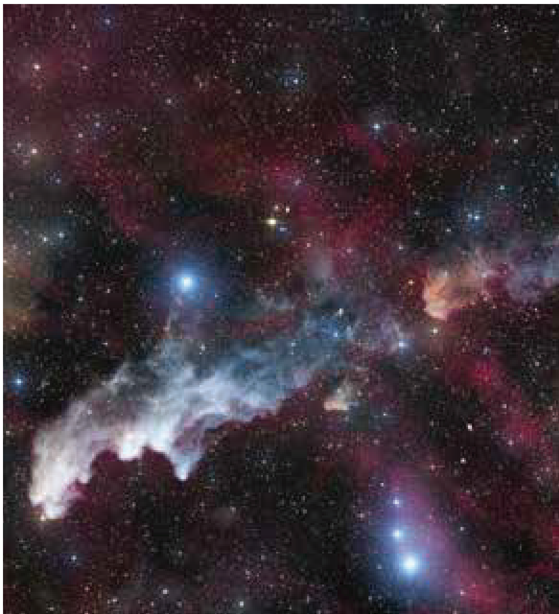
For some of us, this came in the form of astrophotography. Around November 2020, four like-minded people who shared passions for astronomy and photography got to know each other via social media. In December 2020, we formed a group: Astronomads Bangla. The four of us — Basudeb Chakrabarti, Goutam Dey, Samit Saha, and I — were united by our love of the night sky. The formation of the group was a blessing for each one of us. We learned together, photographed the sky together, and most importantly, became friends.

Our progress was slow but definite. Like learning any new skill, it wasn't easy in the beginning. With a lack of local workshops and equipment dealers, we struggled to gather information and to acquire gear. But with patience and endurance, no obstacles seemed insurmountable. We spread our efforts across genres, from nightscapes to solar, planetary, deep-sky, and atmospheric phenomena.

INDIA MAP: *ASTRONOMY*: ROEN KELLY

Bangla: India





We began our astroimaging journey with a few entry-level cameras, camera lenses, and portable trackers. In recent years, we have gotten our hands on dedicated astronomical cameras, small and large telescopes, and larger equatorial mounts. Recently, we invested in some full-frame cameras and lots of additional lenses, especially for nightscape imaging.

That said, our hometown of Kolkata doesn't offer a good view of the night sky, to put it mildly. The light and air pollution from the metropolis' population of 15 million is immense. To combat this, we began taking advantage of remote astrophotography via observatories situated in different regions of the world including Chile, Australia, and Spain.

Over the years, we have striven to improve our photography skills. Our images have won prizes in international

ABOVE: A tapestry of stars stretches across the pre-dawn sky in this image taken in the remote union territory of Ladakh in northern India. Goutam Dey and Soumyadeep Mukherjee used a 50mm lens attached to a Nikon Z6 II.

RIGHT, TOP TO BOTTOM: This image captures the moment when Venus reappeared from behind the Moon after an occultation. Mukherjee captured this with a Nikon D5600 DSLR and a Sigma 150–600mm lens.

At an altitude of 13,862 feet (4,225 m), Pangong Tso in eastern Ladakh is one of the highest lakes in India. This photo shows the Sagittarius Arm of the Milky Way over the Heritage Camp tents where the group stayed for the night. Mukherjee used a Nikon Z6 II mirrorless camera and Tokina 16–28mm lens for the single shot.

Located near the bright star Rigel, IC 2118 is a faint reflection nebula spanning almost 70 light-years and is popularly known as the Witch Head Nebula. Mukherjee used Telescope Live to acquire 12 hours of data from Australia with a Takahashi FSQ106ED, FLI PL16083, Paramount MX+, and Astrodon LRGB filters.

CLOCKWISE FROM TOP LEFT:
The James Webb Space Telescope launches to space aboard its Ariane V rocket, passing the Sculptor Galaxy in this once-in-a-lifetime image. The shot was captured from Sukna, India, by Mukherjee and Samit Saha with a Nikon D5600 DSLR and Samyang 135mm lens.

The interstellar clouds surrounding the star system Rho Ophiuchi comprise one of the closest and most colorful star-forming regions. Basudeb Chakrabarti captured this image with 24 hours of integration from Telescope Live's remote facility in Australia using a Takahashi FSQ106ED, FLI PL16083 CCD camera, Paramount MX+, and Astrodon LRGB filters.

Blue jet lightning and red sprites are rare forms of upper atmosphere lightning — and both are captured in this image against the backdrop of the Milky Way. Mukherjee, Chakrabarti, and Saha took this photograph from Singalila National Park in Nepal with a Nikon D5600 and Tokina 11–16mm.

The cometary globule CG4 is located 1,300 light-years away in the constellation Puppis. Using Telescope Live's ASA 500N 20-inch scope and FLI PL 16083, Mukherjee captured 3.5 hours of data from Chile.

The Belt of Venus, or the anti-twilight arch, is an optical phenomenon caused by the backscattering of sunlight reflected off the dense atmosphere. It's seen as a pink band above the shadow of the rising or setting Earth. This photo was taken from Sadhutar, Nepal, by Mukherjee with a Nikon D5600 and Sigma 50mm lens and shows the Belt of Venus above Mount Everest, the world's tallest mountain.

competitions including the Royal Museums Greenwich's Astronomy Photographer of the Year, the Polish science center Hevelianum's AstroCamera contest, and the Nottingham Precision Astro Engineering (nPAE) competition. Our photos have been published in over 30 different astronomy-related magazines (including this one) and books all over the world. Many of our images have been chosen as NASA's Astronomy Picture of the Day and Earth Science Picture of the Day. We have also had the honor of our images appearing on websites including those of *National Geographic*, *Forbes*, *SpaceWeather*, *EarthSky*, and many more.

Sharing the joy

At first, all the knowledge we gained remained among ourselves. But after a year of working together, we began to think about sharing it with other people in India who were trying to get into astrophotography. Our first dark-sky workshop took place in November 2021, when we traveled with some of our friends to a site with Bortle class 2 skies in northern West Bengal.

Since then, we have gained the experience and skills to share the theoretical and practical knowledge of astrophotography with the people of our country. Starting in mid-2022, we arranged a number of online and offline workshops on astroimaging. We conducted our first public workshop in Singalila National Park, at the border of India and Nepal. We have since conducted workshops in Nepal and India, including in Ladakh at the first Indian dark-sky reserve.

People with vastly different levels of knowledge and skillsets join us — from absolute beginners in photography to people with rich experience in astrophotography. We have tried our best to serve their varying needs. Their joyful reactions when they first capture the Milky Way and see it on the back of their cameras are priceless, and their excitement fuels our own goals and ambitions.

Also in 2022, we organized an astrophotography competition for Indian nationals, which saw more than 160 participants and some unforgettable images. In early 2023, we arranged an exhibition in the heart of Kolkata with around 100 images. The excitement that people have when they first learn about astrophotography — especially that this hobby can be pursued without any professional equipment — is what motivates us to keep sharing the knowledge.

Some of the best and most emotional moments that we experienced during our exhibition were the reactions of children as they took in the images. They seemed more excited than their parents. One little boy, after seeing an image of a galaxy, asked me, "One day, I will also take such photographs, won't I?" My reply was, "Of course, you will." This must be one of the best feelings that one could ever achieve as an astrophotographer.

What lies ahead

With India's population of more than 1.4 billion, it is not an easy task to debunk myths related to astroimaging. We aim to spread the truth — that one does not always require large telescopes or professional gear to photograph nebulae and galaxies. A simple mobile phone or an entry-level DSLR is enough to get started.

The journey, we believe, has only begun. With the wonderful and growing community that we have, the task of spreading the joy of astrophotography is a long one — but exciting nonetheless.

Soumyadeep Mukerjee *is an astrophotographer and founding member of Astronomads Bangla. More information about the group and their work can be found at www.astronomadsbangla.com. He wishes to thank to Ajay Talwar and Chad-Nadir Sciacca for sharing information used in this article.*

A GROWING TRADITION

India has a long history of amateur astrophotography going back to the days of film photography and printed newsletters. But with the advent of the internet and social media, along with the increasing affordability of astroimaging equipment and digital photography, interest in the field has surged in the past few years.

India now has quite a few dedicated astrophotography groups where people meet and interact on a regular basis, both in person and on social media. A few organizations have started producing astrophotography equipment, which will no doubt make those products even more affordable and accessible.

And in 2023, India got its first dark-sky reserve at Hanle in the region of Ladakh. The reserve offers a pristine sky for amateurs as well as professionals — the Indian Astronomical Observatory at Hanle sits at an altitude of 14,800 feet (4,500 meters) and features a 2-meter optical telescope as well as several smaller scopes and a gamma-ray observatory.

In the last few years, Indian astrophotographers have managed to substantially increase their global presence. Just a couple of years ago, India had one of the smallest number of entries in the Royal Museums Greenwich's Astronomy Photographer of the Year (APY) competition. This year, the APY team reported that Indians are the fifth-largest national group to enter the competition. *— S.M.*

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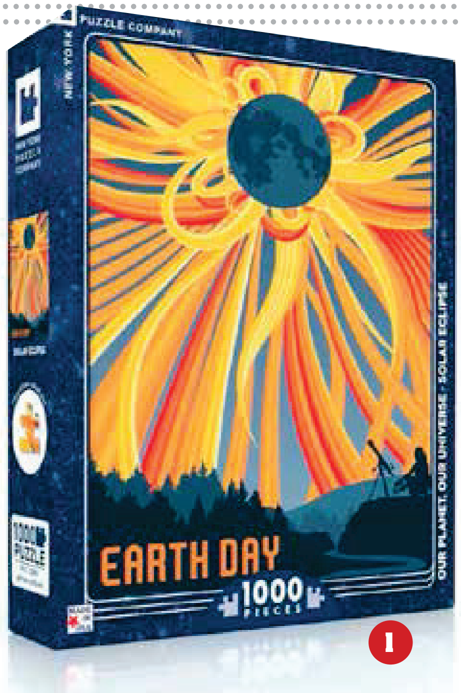

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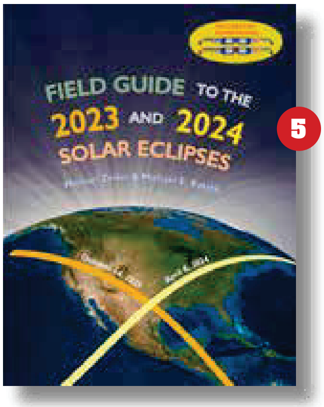

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The upcoming total solar eclipse on April 8, 2024, may be the most observed in history, if the weather cooperates. My advice is to not wait for that day, week, or even month before you start getting ready. To help you do that, here's a list of a couple of dozen items you'll find either useful on eclipse day or just plain fun. They're listed below in no particular order.

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1 New York Puzzle Company Solar Eclipse Puzzle

If you want a fun activity before or after (but not during!) April's eclipse, this puzzle might be for you. The stunning artwork was created by NASA Science Art Director Jenny Mottar. This 1,000-piece puzzle measures 19.25 inches by 26.625 inches (49 centimeters by 68 centimeters). **$25** ▪ **https://newyorkpuzzlecompany.com**

2 Celestron Eclipsmart 10x42 Porro Solar Binoculars

These binoculars are specially designed so that nothing but the Sun can be seen through them. They have built-in filters that meet the ISO 12312-2 safety standard. With a 6° field of view and 12.7 mm of eye relief, you'll have no trouble locating the Sun. The binoculars have a rubber-armored aluminum housing and folding eyecups. **$87.95** ▪ **www.celestron.com**

3 Daystar Eclipse Glasses

Daystar manufactures their own eclipse eyeglasses in six designs, all of which comply with the ISO 12312-2 filter transmission requirements — meaning they block out certain amounts of UV and infrared radiation. Because they cut the Sun's light to 1/1,000 of 1 percent, they're safe for direct viewing. And if you're a part of a group, buying more than nine pairs can get you a quantity discount. **$2** ▪ **www.daystarfilters.com**

4 Rainbow Symphony Solar Shield

If you want to handhold a solar filter but are worried about a piece of welder's glass breaking, Rainbow Symphony's Solar Shield is an excellent alternative. The company uses a black polymer with an optical density of grade 5 to protect your eyes. The laminated holder measures 8.5 inches by 5.5 inches (21.6 cm by 14 cm) and the opening is 2 inches by 4 inches (5.1 cm by 10.2 cm). **$4.95** ▪ **www.rainbowsymphony.com**

ECLIPSE PRODUCTS

These items will turn upcoming eclipses into lasting memories.

BY MICHAEL E. BAKICH

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5 Great American Eclipse Field Guide

The *Field Guide to the 2023 and 2024 Solar Eclipses* includes everything you need to know about the Oct. 14, 2023, annular solar eclipse and the upcoming April total solar eclipse. It contains detailed maps by Michael Zeiler showing the eclipse paths at several different scales, from regional to local. The book also comes with two pairs of eclipse glasses. **$20** ▪ **www.greatamericaneclipse.com**

6 Celestron Eclipsmart 2x Power Viewers Observing Kit

If you've ever thought regular eclipse glasses just don't make the Sun big enough, this kit is for you. In it, you'll find a double-sided eclipse map and two pairs of 2x solar glasses. Both glasses meet the ISO 12312-2 safety certification, give the Sun a natural orange tint and fold flat for easy storage. **$12.95** ▪ **www.celestron.com**

7 Educational Innovations Sunspotter Solar Telescope

This folded-Keplerian telescope is both easy to use and safe for all ages because you don't look through it. Instead, the Sunspotter projects a bright image of the Sun on any white surface you attach. It's great for viewing the partial phases of the eclipse or anytime you're looking for sunspots. **$499.95** ▪ **www.teachersource.com**

8 The Lunar Shadow 2024 Total Solar Eclipse Mug

Drink your umbra-dark coffee the morning of the eclipse in style. This company offers four styles of ceramic coffee mugs. Two mugs feature an attractive graphic, and one shows the path. All are 3.85 inches (9.8 cm) high and 3.35 inches (8.5 cm) in diameter, and are dishwasher and microwave safe. **$16.99** ▪ **www.thelunarshadow.com**

9 Great American Eclipse 2024 Map

This map of April's total solar eclipse is available in two sizes: 11 inches by 17 inches (28 cm by 43 cm) or 22 inches by 34 inches (56 cm by 86 cm). The map shows the path and time of the eclipse, as well as its duration, in both local and Universal Time. It names hundreds of locations across Mexico, the U.S., and Canada, and is printed on glossy heavy card stock for added durability. **$8 and $20** ▪ **www.greatamericaneclipse.com**

10 Daystar Universal Solar Filters

These filters — which ship flat and are folded into shape — come in three sizes to cover your optics: 50mm to 69mm, 65mm to 80mm, and 80mm to 90mm. All conform to the ISO 12312-2 standard. They fit binoculars, cameras, spotting scopes, and small telescopes. **$16.95 to $29.95** ▪ **www.daystarfilters.com**

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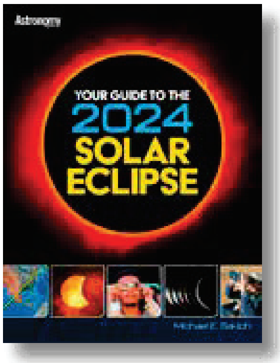

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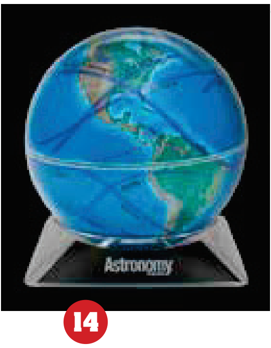

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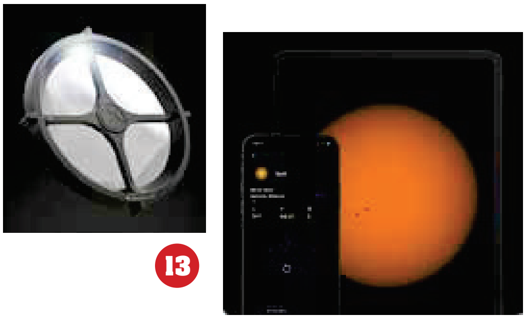

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11 Solar Snap — The Eclipse App

If you want to cleverly snap shots of the eclipse with your cellphone, this kit has what you need. It includes two ISO 12312-2 certified camera filters with Velcro pads for attaching to your phone, two pairs of solar glasses, and an eclipse photo app for Apple or Android. **$12.99 ▪ MyScienceShop.com**

12 *Astronomy's Your Guide to the 2024 Total Solar Eclipse*

This full-color book has all the information you'll need for the 2024 total solar eclipse. It contains maps of the path of totality, and information on safely observing eclipses and on the phenomena that occur during an eclipse. You can also learn how to choose the best equipment for viewing and photographing the event, how to use weather forecasts to maximize your chances of catching the eclipse, and much more. **$24.99 ▪ MyScienceShop.com**

13 Unistellar Smart Solar Filter

If you own either version of Unistellar's eVscope or eQuinox, this is the solar filter to have in your kit. The company incorporated a polymer filter that reduces the Sun's light by 100,000x. The overall diameter is 5.6 inches (143 mm) and the polymer's diameter is 4.6 inches (116 mm). **$249 ▪ www.unistellar.com**

14 *Astronomy's* 6" Eclipse Globe

Retired NASA astrophysicist and eclipse expert Fred Espenak designed this custom 6-inch (15 cm) globe for *Astronomy.* It shows the path of every total solar eclipse between 2021 to 2070 in high resolution. The injection-molded globe comes with an acrylic base for display as well as an informational guide. **$34.95 ▪ MyScienceShop.com**

15 Great American Eclipse Glow-in-the-Dark Corona Shirt

This cotton T-shirt features a glow-in-the-dark solar corona image on the front and the path of the April 8, 2024, solar eclipse with cities from Mazatlán to Newfoundland listed concert-style on the back. It is available in adult sizes, ladies' cut, and children's sizes. **$25 ▪ www.greatamericaneclipse.com**

16 Celestron Eight-Piece Solar Eclipse Kit

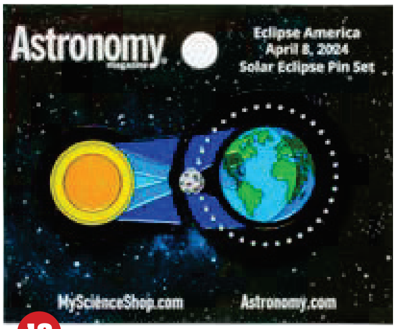
If you're observing with your family or a small group, this kit might fill all your needs. It contains four pairs of cardboard eclipse glasses, one pair of plastic eclipse glasses, one solar-safe photo filter, a 32-page eclipse guide booklet, and a double-sided eclipse map. All glasses meet the ISO 12312-2 safety standard. **$39.95 ▪ www.celestron.com**

17 Great American Eclipse Eclipser HD Solar Glasses

If the less-expensive cardboard eclipse glasses just aren't your style, upgrade to this folding plastic model. The filters, which give an orange hue to the Sun, are scratch-resistant polymer that meets the ISO 12312-2 standard, cutting the Sun's light to 1/100,000 of its normal intensity. **$20 ▪ www.greatamericaneclipse.com**

18 *Astronomy's* Eclipse Pin Set

This set of three pins combines to show the geometry of a total solar eclipse. You can wear them individually or as a set. The assembled trio measures approximately 3¼ inches (8.3 cm) across. **$18 ▪ MyScienceShop.com**



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19 Great American Eclipse Texan Eclipses Map

This map of the Lone Star State shows the intersection of the paths of the Oct. 14, 2023, annular eclipse and the April 8, 2024, total eclipse. The map is printed on glossy poster card stock. It measures 27 inches by 29 inches (69 cm by 74 cm). **$18** ▪ **www.greatamericaneclipse.com**

20 Coronado SolarMax II 90 Double Stack Solar Telescope

This Hydrogen-alpha (Hα) telescope has a 0.5-angstrom bandpass width that reveals both prominences and surface detail. The thermally stable filter won't drift off the Hα line as it heats up during use. The star diagonal features a built-in blocking filter and offers a full-disk view of the Sun. **$6,499.99** ▪ **www.meade.com**

21 Great American Eclipse Solar Eclipse Globe

This 12-inch-diameter globe shows the paths of every total solar eclipse of the 21st century. This includes 68 total solar eclipses and seven annular-total (hybrid) solar eclipses. **$95** ▪ **www.greatamericaneclipse.com**

22 Daystar Solar Scout SS60-ds Telescope

If you want to view the eclipse in Hydrogen-alpha light, look no further than Daystar's 2.4-inch Solar Scout. The helical front-focus feature keeps the eyepiece still while using the tuning knob to shift the central wavelength by 0.5 angstrom higher or lower. A Vixen-style mounting foot allows easy connection to a mount. For an additional $200, Daystar will supply a star diagonal, 25mm eyepiece, wall power adapter, and a 10,000 mAh battery. **$995** ▪ **www.daystarfilters.com**

23 Commemorative 2024 Total Solar Eclipse Coin

This 1.75-inch (44.5 mm) coin depicts the path of April's totality across the U.S. in full color. On the opposite side, the cone of the Moon's dark inner shadow is shown above the location at the Texas/Mexico border where totality is longest in the U.S. The coin weighs 1.4 ounces (39.6 grams); a clear plastic sleeve is provided for protection. **$15.95** ▪ **www.eclipsesofthesun.com**

24 RX Safety Solar Eclipse Glasses, Shade 14

You'll certainly stand out on eclipse day with RX Safety's solar eclipse glasses or goggles. Each lens is made of #14 welder's glass, which are approved for solar viewing. The glasses measure 5.3 inches wide by 5.5 inches long by 1.7 inches high (13.5 cm by 14 cm by 4.3 cm) and the goggles measure 7 inches by 2 inches high (17.5 cm by 5 cm) and attach to your head with a strap. **$29.99 or $54.99** ▪ **https://rx-safety.com**

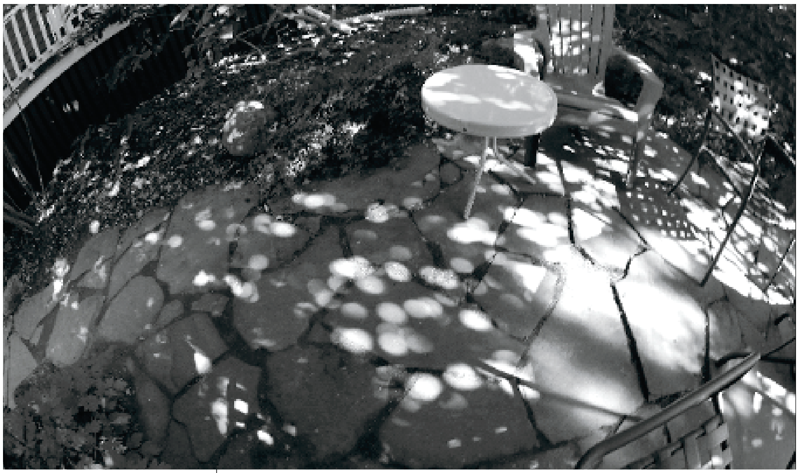
25 Celestron EclipSmart Travel Solar Scope 50

This 2-inch dedicated solar refractor features an f/7.2 focal ratio and fully coated lenses that conform to the ISO 12312-2 safety standard. It comes with a solar-safe finder scope, a star diagonal, a 20mm eyepiece that gives a magnification of 18x, an alt-azimuth mount, a tripod, and a backpack that holds it all. **$129.95** ▪ **https://celestron.com**

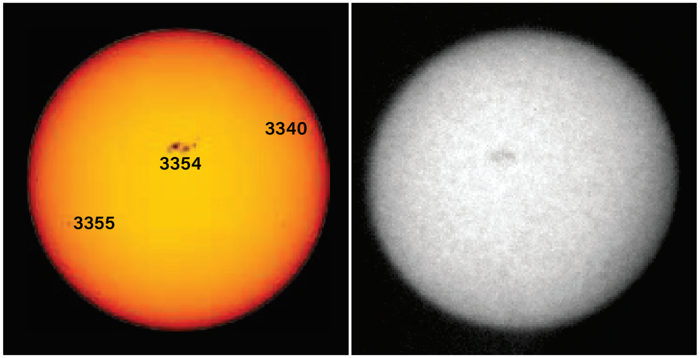
***Michael E. Bakich** is a contributing editor of* Astronomy *who has a vast collection of eclipse-related products.*

Seeing sunspots on paper

Nature's light reveals nature's magic.



ABOVE: The full disk of the Sun projected multiple times onto the ground via pinhole spaces between the leaves of a tree. The challenge is to find a Goldilocks disk — one crisp enough to reveal a naked-eye sunspot. STEPHEN J. O'MEARA



RIGHT: The giant sunspot AR 3354 on June 29, 2023, imaged by SDO (left) and by Stephen O'Meara on the floor from a hole in a roof (right).

BY STEPHEN JAMES O'MEARA

Stephen is a globe-trotting observer who is always looking for the next great celestial event.

During partial phases of a solar eclipse, one popular activity is to project and capture solar crescents when trees are in leaf. Tiny spaces between leaves can act as natural pinhole cameras, projecting dozens of solar crescent images on the ground. But such projections aren't only visible when there's an eclipse — they can display the Sun as full circles of light on any sunny day.

With solar sunspot activity soaring and naked-eye sunspots on the rise, I wondered if these natural solar projections would provide crisp enough images to display naked-eye sunspots. Turns out, they can.

The crispness of the image depends on how far away the pinhole is from the surface that it is projected upon. (A piece of paper or cardboard works well.) When the pinhole is close to the surface, the image is rather sharp. But there's a trade-off: The shorter distance causes the sharp image to be smaller and brighter — sometimes too small and intense to see a naked-eye sunspot. Conversely, if you stand too far away, the image will appear larger and fuzzier, washing out any definition of smaller naked-eye sunspots. This is where finding a Goldilocks position is key.

Solar circles

My initial studies reveal that a solar disk about 1 to 2 inches (2.5 to 5 centimeters) in diameter is ideal. This, however, is a work in progress, so your results may differ. Finding the best projected discs requires a critical and patient survey of all the disks projected onto your surface. The circles can pulse in and out of focus, or nervously overlap, especially when the wind blows. It takes time.

Moderately dim disks seem to work best. Patience is also key in this activity, so be sure to scan and even rescan the images. Using a larger tree (with enough gaps to create projections) vs. a smaller tree that's more susceptible to the wind will help greatly.

Targeting sunspots

This leads us to the question of how large of a spot a natural "pinhole" can show. Again, your results may vary. I find when looking through a No. 14 welder's glass directly at the Sun, I can usually detect sunspots that span about 1.5 Earth diameters or more. Naturally, the larger the solar spot, the easier it is to see. If you don't have solar-safe glasses, the website of NASA's Solar Dynamics Observatory (https://sdo.gsfc.nasa.gov) offers daily images of the Sun.

My first projected sunspot occurred in May 2023, around the time when complex (and highly elongated) AR 3315 appeared on the Sun's face. Although I first saw the spot through a No. 14 welder's glass on May 25, I did not see it via projection until May 27, when it was about 5 Earth diameters. A special day came on June 29, when AR 3354 rapidly grew to 10 Earth diameters. It was so large that I easily saw it projected onto the floor of a dance studio through an artificial hole in the roof. I was able to follow AR 3354 by leaf-hole projection until July 2, when it shrank to about 2 Earth diameters on one remarkably crisp projection.

The reigning sunspot to date is AR 3363 — the same spot that the Perseverance rover imaged from the surface of Mars. I was able to naturally project its image on July 8 — two days after it first appeared on the Sun's disk. I then followed it daily as the Sun rotated.

Projecting natural sunspots is truly a challenge. If you succeed, I would love to hear about it; as always, send what you see or don't see to sjomeara31@gmail.com.

BROWSE THE "SECRET SKY" ARCHIVE AT
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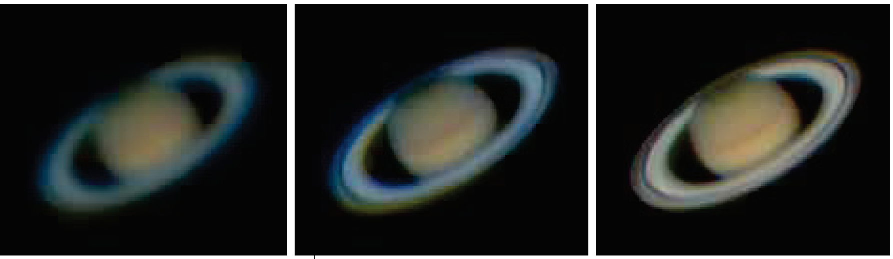
Try your luck

You can capture clear photographs of the solar system with lucky imaging.

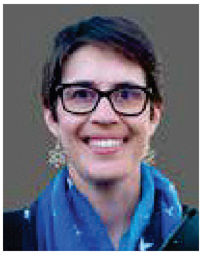


This trio shows Saturn in a Celestron 8-inch Schmidt-Cassegrain and ZWO ASI120MM with LRGB filters, on a night of unusually good seeing.

LEFT: A stacked image from AutoStakkert!.

CENTER: Wavelet deconvolution in RegiStax.

RIGHT: Post-processed in PixInsight. MOLLY WAKELING



BY MOLLY WAKELING

Molly is an avid astrophotographer active in STEM outreach. She is pursuing her Ph.D. in nuclear engineering.

How do astroimagers get such sharp images of the Sun, Moon, and planets? The answer is a technique called lucky imaging. As every astronomer has witnessed, the atmosphere roils with waves as hot and cold air mix, causing our neighboring celestial bodies to blur at the eyepiece or in the camera. Fortunately, lucky imaging can beat the seeing and allow us Earth-bound mortals to sharply capture the heavens.

The science

In the chaos of the movement of air in the atmosphere, brief moments of clarity exist between your telescope and outer space. A camera running at a high frame rate will capture some frames during those lucky moments. These are then sorted by quality using software such as AutoStakkert! or RegiStax, and a cut is made to keep the best frames and toss the rest. The remaining frames are stacked, which produces an image that initially appears blurry. You then apply an algorithm called wavelet deconvolution, which is some complicated math covered up with simple sliders to adjust the amount of sharpening applied to different sizes of pixel groupings. The clear, sharp result is nothing short of magical.

> **In the chaos of the movement of air in the atmosphere, brief moments of clarity exist between your telescope and outer space.**

The method

To do lucky imaging, you need a telescope, a high-speed USB 3.0 camera, and preferably a computer with a speedy solid-state drive and USB 3.0 ports. The ability to record at a high frame rate — which is determined by the data transfer speed and camera's read speed — allows more frames to be captured in those brief moments of good atmosphere.

One way to increase the frame rate is to use a region of interest (ROI), where the software only captures a smaller part of the image inside a user-defined box and discards the rest. Another way is to increase the gain so that you can shorten the exposure time.

Shooting with a long-focal-length telescope will reveal more detail, but even shorter-focal-length instruments, including refractors, can capture a nice image. Because the planets, Sun, and Moon are so bright, many use a Barlow for additional magnification without worrying much about losing brightness.

The camera does not need to be fancy; a small-sensor uncooled camera, like those used for autoguiding, will do. These go for as little as $150. It can be a color camera or a monochrome camera with filters. Rather than taking individual images, you will instead capture video, taking a few hundred to a few thousand frames. Saving to the AVI format works, but it can be tricky to process as the frames may be compressed in various and opaque codecs. A better option is SER, a raw video format specifically for astronomy, much like FITS is for single images. My favorite app for video acquisition is SharpCap, while some favor FireCapture or ZWO's ASICap.

My recommendation for processing is to do the sorting and stacking in AutoStakkert! and the wavelet deconvolution in RegiStax, followed by cropping, color corrections, denoising, and other improvements in Photoshop, PixInsight, GIMP, or any other post-processing software you prefer. There isn't room to describe the whole editing process here, but there are a number of helpful video and written tutorials online.

Some targets have specific limitations. For instance, Jupiter has a fast rotation period (about 10 hours), which means in order to avoid blurring, the total video length should be kept under about 90 seconds. This is tricky if you are imaging in monochrome and need three videos (red, green, and blue), but with a fast camera it is possible. You can go a little longer by taking short videos back to back and using WinJupos, a program that derotates Jupiter (as well as the other planets, Sun, and Moon). Rotation on Mars and Saturn will also become apparent after more than about five minutes, depending on your total focal length. Features on the Sun change rapidly, so it is best to keep those videos short as well.

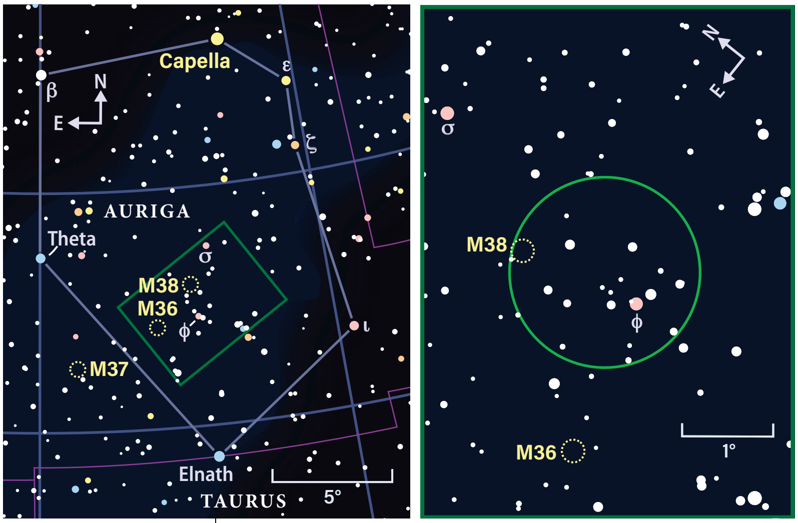
Give it a try!

You too can capture sharp and beautiful images of our solar system neighbors with lucky imaging. Local seeing conditions are a limiting factor — when atmospheric turbulence is at its worst, you can only compensate to a certain degree. But keep at it — you're bound to get a steady night eventually.

BROWSE THE "OBSERVING BASICS" ARCHIVE AT **www.Astronomy.com/author/molly-wakeling**

Winter's first act

Dash through the Auriga's stars and asterisms.



Travel southeast from Capella to capture Auriga's targets. The chart at right zooms in on the Happy Face asterism. *ASTRONOMY:* ROEN KELLY

BY PHIL HARRINGTON

Phil received the Walter Scott Houston Award at Stellafane 2018 for his lifelong work promoting and teaching astronomy.

Even though winter doesn't officially begin until Dec. 21, one glance at the current evening sky shows that it is on its way. The 20th century's preeminent deep-sky author, Walter Scott Houston, once wrote of the late autumn sky, "The celestial actors are in place, a serene majesty washes over the stage, and I can hear the music of galactic trumpets in their opening bar. What better time to observe the splendor of the heavens?"

The first of the season's many bright celestial actors, **Capella** (Alpha [α] Aurigae), ushers in winter's first act. It brings with it a collection of striking binocular targets stashed within its constellation, Auriga the Charioteer.

Capella, at magnitude 0.08, is the sixth brightest star in the sky and lies approximately 43 light-years from Earth. It's a dazzling sight through binoculars. Although it looks like a single point, the star we see is a binary system made up of two closely set yellow giants. View Capella high in the sky and you might see the faintest hint of yellow.

It's a dazzling sight through binoculars.

As it passes centrally through Auriga, the Milky Way brings several open star clusters that are eager to show themselves through binoculars. The brightest three hold sequential spots in Charles Messier's catalog — M36, M37, and M38 — although he did not discover any of them. All were first spotted by Giovanni Battista Hodierna. Using a simple 20x refractor, he cataloged 40 nebulous objects. Hodierna published those observations in 1654.

All three objects fit into the same 7°-wide field of view. If you are using 10x or lower-powered binoculars, once you spot one, you might be able to catch all at once.

Let's start our tour with a smile. If you aim 6° due north of Elnath (Beta [β] Tauri), the tip of Taurus' western horn, you'll find an arc of six 5th- to 7th-magnitude stars curving northeast to southwest. The brightest is 5th-magnitude Phi (φ) Aurigae. To the arc's west are two other 6th-magnitude stars. Together, they form an asterism known to many as the **Happy Face**. I sometimes imagine it as Shirley Temple, the dimpled child star of the 1930s, because our heavenly grin also has a hazy dimple just off the northernmost star in the smile.

That dimple is actually the open cluster **M38**. Look for what seems like a cotton ball two-thirds the size of the Full Moon floating in a starry field. Over 100 suns make up M38, although the brightest only rank 7th magnitude. Naturally, the larger the binocular, the greater the number of stars seen. Those viewing through 70mm or larger binoculars may notice that some of the stars form a cross or an X against the glow of unresolved starlight.

Just 2.3° southeast of M38, we come to **M36**. M36 appears smaller than M38. Its stars, however, are brighter, which makes it easier to resolve. Depending on local sky conditions as well as the size and quality of your binoculars, you might be able to spot more than half a dozen faint stars within its round, misty glow. Through giant binoculars and telescopes, some of the cluster stars appear to line up in curves that hook away from the center, leading to M36's nickname, the Pinwheel Cluster.

Our final scene is just beyond the southeast side of Auriga's pentagonal frame. **M37** is the brightest of the three Messier objects here, although it can be challenging to find. Aim just east of the halfway point on a line between Elnath in Taurus and Theta (θ) Aurigae.

M37 is also the richest of the three Messier objects here, with over 1,800 stars calling it home. But because most are fainter than 10th magnitude, it's also the most difficult to resolve. Most binoculars show a large circular glow against a star-filled field. My 16x70 binoculars begin to add a granularity to the glow as dimmer inhabitants begin to appear. That glittery appearance resulted in M37 being nicknamed the Salt and Pepper Cluster.

Questions, comments, suggestions? Contact me through my website, philharrington.net. Until next time, remember that two eyes are better than one.

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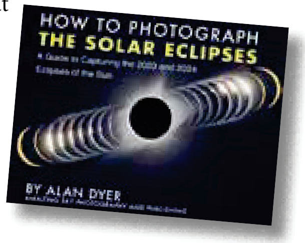
Capturing eclipses

Amazing Sky
Strathmore, Alberta

How to Photograph the Solar Eclipses is the newest guide from renowned astrophotographer Alan Dyer. This 350-page ebook explains techniques for shooting the upcoming eclipses with stills, video, and time-lapses. Other advice includes what not to do, equipment, image processing, and more.



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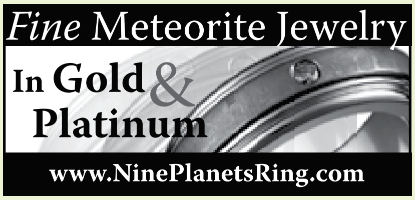
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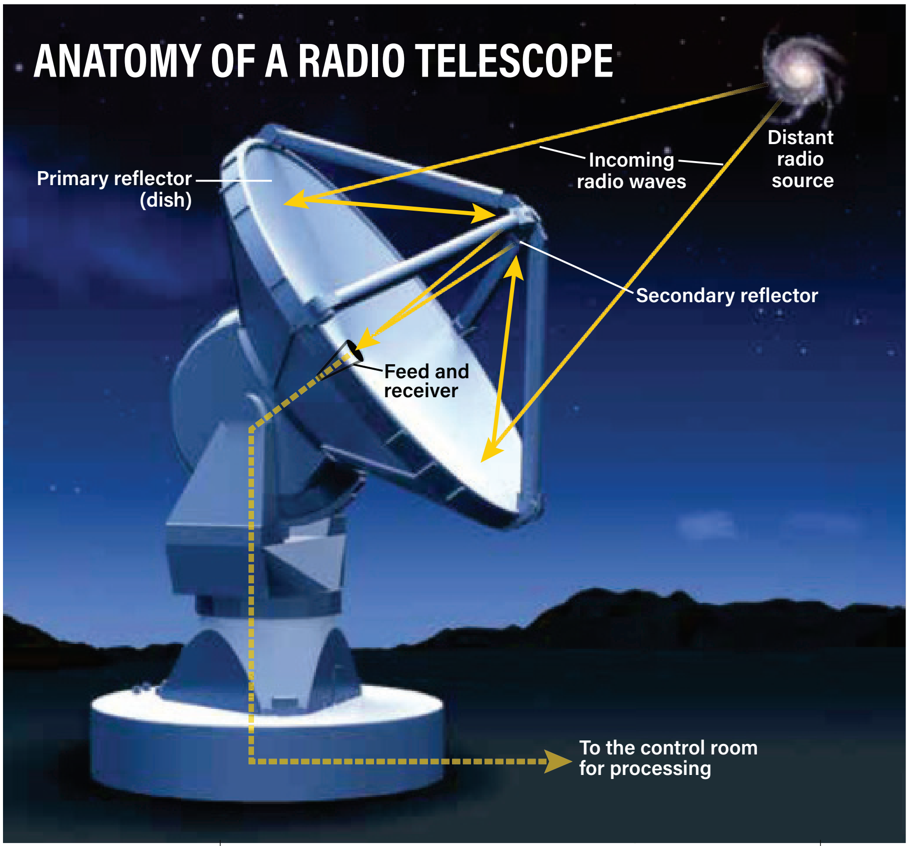


Radio telescopes observe by reflecting incoming radio waves to a point above the dish. A secondary reflector bounces the waves back toward the center of the dish, where feeds convert and send the signal to receivers below.

ASTRONOMY: ROEN KELLY, 3D MODEL: ALMA (ESO/NAOJ/NRAO)/DAVID CHORLTON

Radio astronomy

Q | HOW ARE IMAGES MADE WITH RADIO TELESCOPES?

Steve Hepp
Montesano, Washington

A | Radio telescopes come in all shapes and sizes, depending mainly on the radio wavelengths they are designed to receive. The most familiar sort is a curved dish that reflects radio waves to a focal point, ranging from meter to submillimeter wavelengths. Usually, radio waves are reflected by a smaller secondary reflector back down to the center of the dish, where it is much more convenient to place feeds (which convert the radio waves to electrical signals) and receivers.

If there were only one feed at the exact focal point, the telescope would only be sensitive to radio waves from one small patch of sky, whose diameter (in degrees) is roughly 57.3 times the observing wavelength divided by the diameter of the dish. This would be like a single pixel in an optical image. Imaging an extended object or surveying large swaths of sky becomes excruciatingly time consuming, building up the image one pixel at a time.

Fortunately, there is a region around the precise focal point where radio waves are still in reasonably good focus. A second feed and receiver just off axis can observe a patch of sky adjacent to the first and you will have two pixels! Clever electronics and engineering reduce distortions from being off axis. That region is only big enough to accommodate half a dozen or so separate feeds and receivers, but that is still an enormous increase in speed and sensitivity.

Since about 1980, nearly all large radio dishes incorporate systems similar to the one described above. Crowding the feeds together places more beams on the sky, but these are difficult to build because the feeds interact with each other. These are called phased focal plane arrays. The 100-meter Green Bank Telescope in West Virginia has a seven-beam system for surveying interstellar ammonia at a wavelength of 1.3 centimeters. A 16-beam system operating at a 3-millimeter wavelength observes carbon monoxide and other molecules. Larger multi-beam systems are installed on arrays in Australia and the Netherlands.

John Wardle
Professor of Astrophysics, Brandeis University, Waltham, Massachusetts

Q | DO BLACK HOLES HAVE CENTERS? IF SO, WHAT'S GOING ON IN THERE?

Richard Livitski
Seal Beach, California

A | Einstein spent 10 years wrestling with three fundamental concepts in physics: acceleration, the special theory of relativity, and the gravitational force. This heroic effort culminated in 1915 with the general theory of relativity, an elegant set of equations relating the curvature of space-time to the matter moving around in it.

Though simple to write down, finding solutions to these equations has intrigued physicists and mathematicians ever since. To tackle any set of equations relating a physical system that evolves with time, a good start is to make assumptions that simplify things. Barely a month after Einstein's publication, Karl Schwarzschild discovered one of the simplest solutions. His description relating a compact spherically symmetric mass that doesn't change with time to the curvature of space-time surrounding it introduced us to what we now call a black hole.

Initially this solution was dismissed by many because it predicted an unusual situation: All matter in a black hole

Open star clusters like NGC 2547 (left) form and stay in galactic disks, while globular clusters like 47 Tucanae (NGC 104; right) may be kicked out of such regions and into the halo shortly after forming. ESO; ESO/M.-R. CIONI/VISTA MAGELLANIC CLOUD SURVEY. ACKNOWLEDGMENT: CAMBRIDGE ASTRONOMICAL SURVEY UNIT

is concentrated into a central point of infinite density and infinitesimally small size — a singularity. Singularities make physicists rather uncomfortable.

Having established what's at the center, what about the empty space immediately surrounding the singularity? Consider the trajectory of a spaceship falling into a black hole. From the point of view of a distant observer, the ship will accelerate and quickly reach the central singularity, but on the way it passes a point of no return: the event horizon. The closer to the central mass, the stronger the force of attraction; inside the event horizon the force is so strong — equivalently, the space-time is so curved — that no engine is powerful enough to overcome gravity and drive the ship outward. In fact, inside this radius, not even light can move fast enough to escape the attraction of the singularity. Just outside the event horizon, ships still travel on unusual paths, but at least they can return home.

The two problems keeping physicists up at night are 1) that our understanding of quantum mechanics makes the idea of a singularity untenable, and 2) the event horizon shields us from measuring what happens inside a black hole. These issues bring us to the cutting edge of theoretical physics: bridging general relativity and the quantum realm; reconciling the event horizons of black holes with the laws of thermodynamics; and even speculating about wormholes, where the center of a black hole is a pathway rather than a singularly unfortunate dead end.

Mark Avara
Astrophysicist, Institute of Astronomy, Cambridge, University of Cambridge, U.K.

Q WHY ARE OPEN STAR CLUSTERS IN THE DISK OF A SPIRAL GALAXY, WHILE GLOBULARS ARE IN THE HALO? IS THE SAME TRUE FOR IRREGULAR AND ELLIPTICAL GALAXIES?

Leonard C. Boucek
Monmouth Junction, New Jersey

A The differences in location between open and globular star clusters result from the interplay between gravity and rotational motion. This rotational motion is called angular momentum, and is a conserved quantity. It is what keeps planets orbiting stars instead of succumbing to gravity and spiraling inward.

Angular momentum helps organize matter into disks. Disk-forming scenarios start with gravitationally bound matter with random motions. Over time, as this cloud of matter contracts and begins to orbit a common center of mass, collisions between particles cancel out their random motions and they converge, forming a spinning, flat disk.

From this tug-of-war between gravity and angular momentum, the gas and dust in a spiral galaxy lie close to the plane of the galactic disk, in a region we call the thin disk. The abundance of such material there is why the young star-forming open clusters are located preferentially in the thin disk. Once young stars leave their open cluster cradles, gravitational interaction with the multitude of other stars in the galaxy causes their motions to become more complex, eventually forming the thick disk of older stars enveloping the thin disk of younger stars.

Globular clusters are also formed in gas-rich environments similar to galactic disks, but with higher gas pressure. We believe globular clusters are now mostly in the galactic halo because these old systems were kicked out of those high-pressure, gas-rich regions relatively early, therefore undergoing less gravitational disruption ever since. This is likely also the reason why globular clusters are significantly more massive than open clusters.

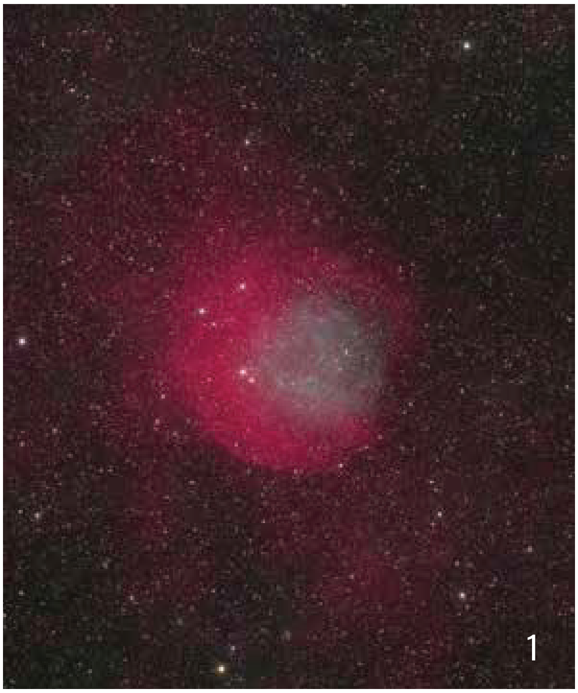
It is hard to define different components in elliptical or irregular galaxies. Ellipticals have stellar populations billions of years old, where globulars are much more common. At such ages, typical open clusters have dissolved into the smooth stellar component of their parent galaxy.

Serge Dieterich & Paul Goudfrooij
HST Instrument Scientist & JWST Instrument Scientist, Space Telescope Science Institute, Baltimore, Maryland

SEND US YOUR QUESTIONS

Send your astronomy questions via email to **askastro@astronomy.com**, or write to Ask Astro, P.O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

Cosmic portraits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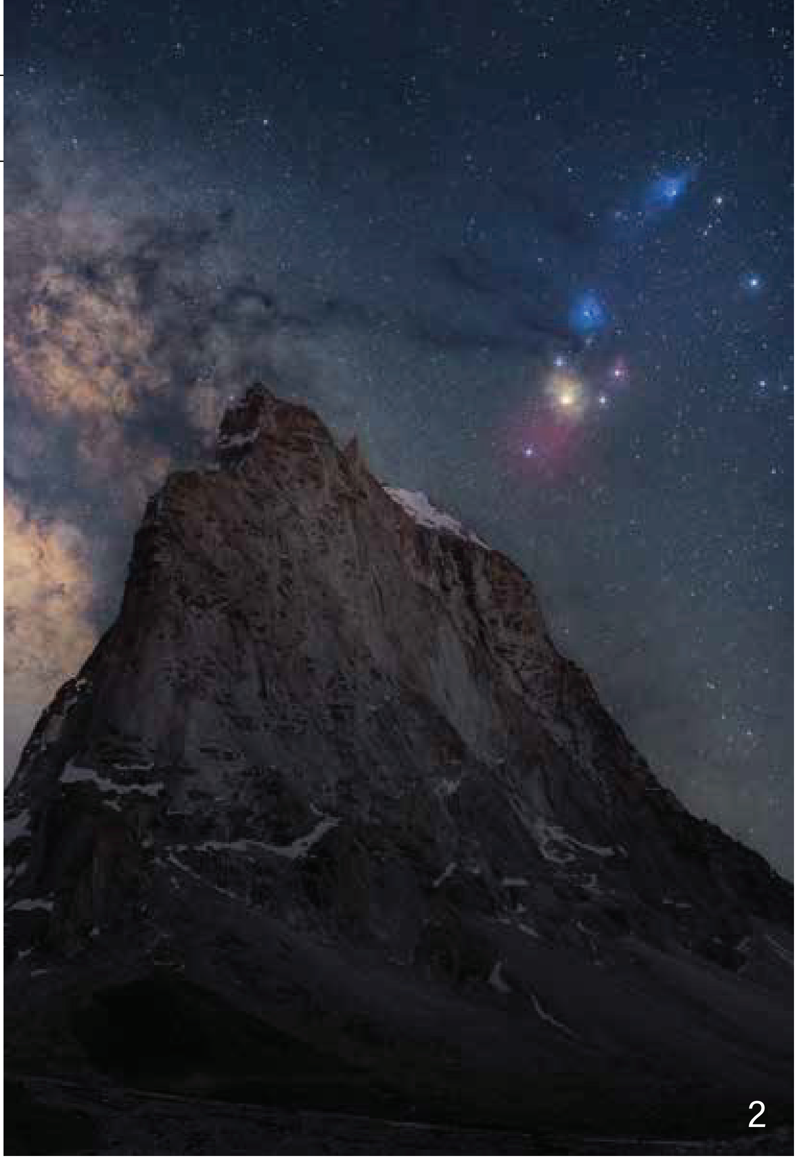
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1. PLANETARY POTENTIAL
FP J1912–0331 is a planetary nebula candidate in Aquila. It's situated close to the Milky Way, making it hard to photograph. This HOO image represents 35.1 hours of exposure with a 6-inch scope. It features an inner shell of OIII surrounded by a faint outer hydrogen shell. ▪ ***Jon Talbot***

2. CLOUD-TOPPED PEAK
The Milky Way and the colorful star-forming Rho Ophiuchi cloud complex hang over the face of Gumbok Rangan, a peak in the Ladakh region of India. Standing roughly 3,300 feet (1,000 m) above its base, it is referred to as God's Mountain by local practitioners of Tibetan Buddhism. The photographer used a modified DSLR and a 28mm lens, shooting the sky with thirty-three 30-second light frames (and six darks) at f/2.2 and ISO 1600 and the mountain with a 2.5-second exposure at f/5.6 and ISO 100. ▪ ***Soumya Banerjee***

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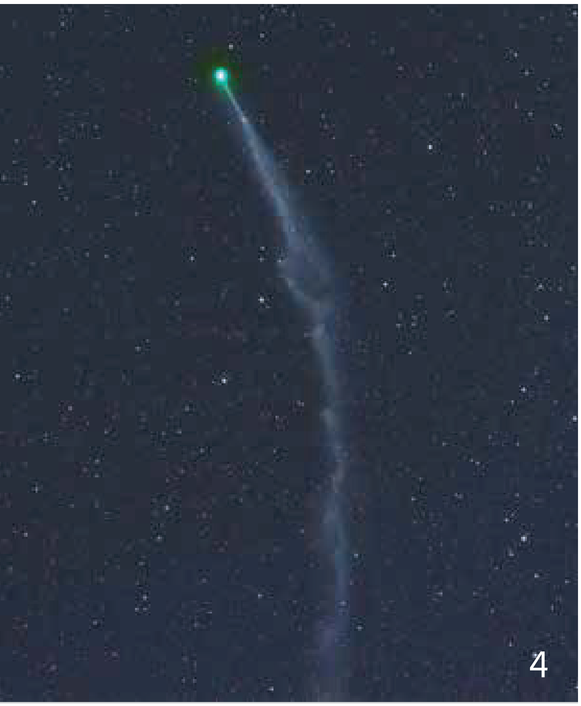
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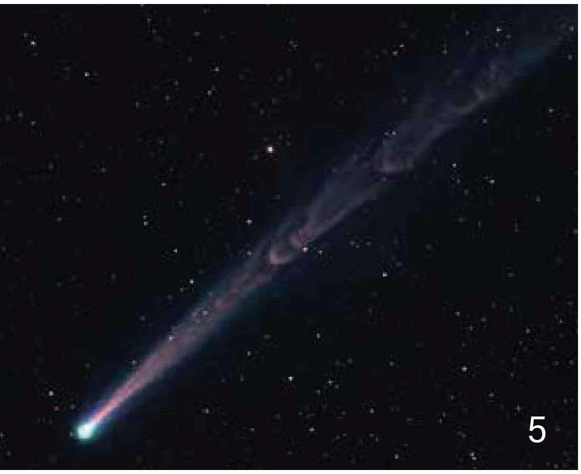
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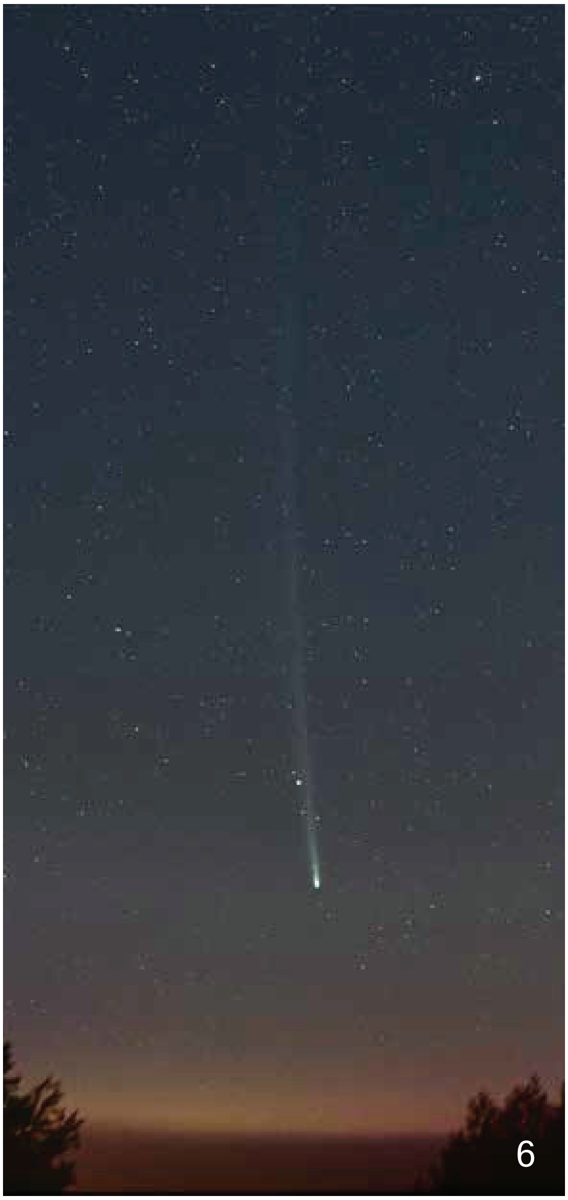
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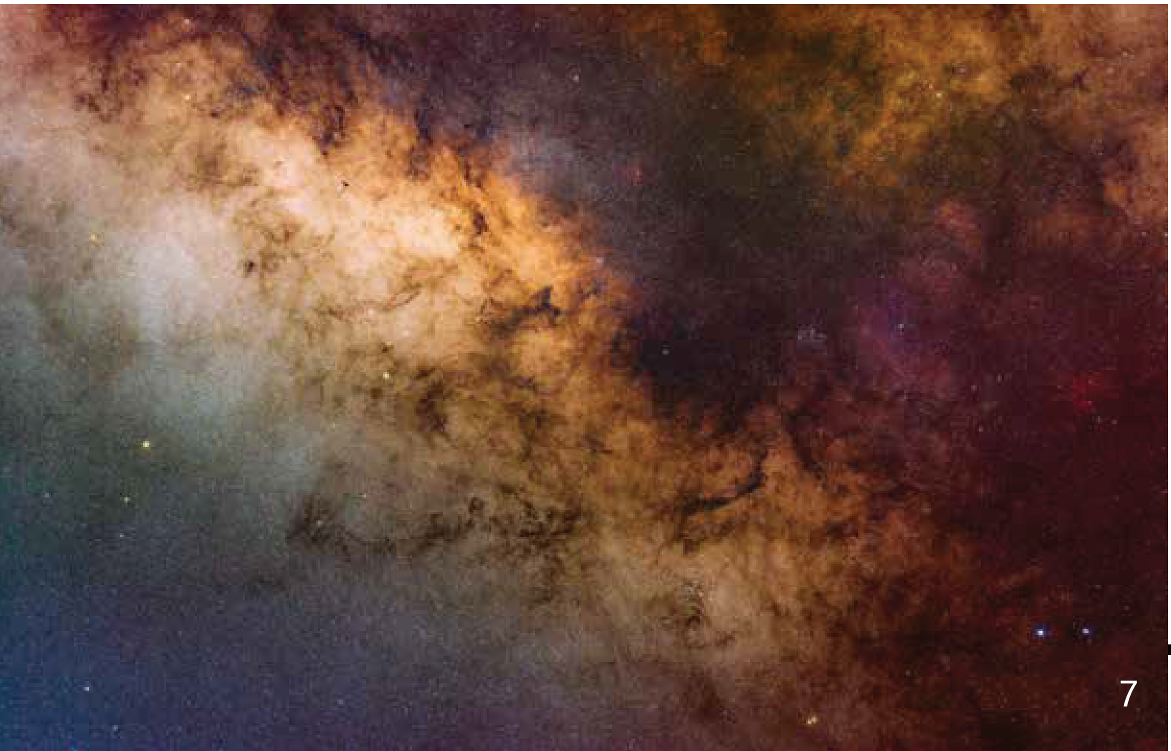
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3. PARTLY CLOUDY SKIES
The Small Sagittarius Star Cloud (M24) is not a single object but rather the nebulous appearance of a section of stars in the Milky Way framed by dust. This starscape is dotted by dark tendrils of dust, the two most prominent of which are Barnard 92/3. This image was taken with seven hours of exposure with a 7-inch scope.
· *Emmanuel Delgadillo*

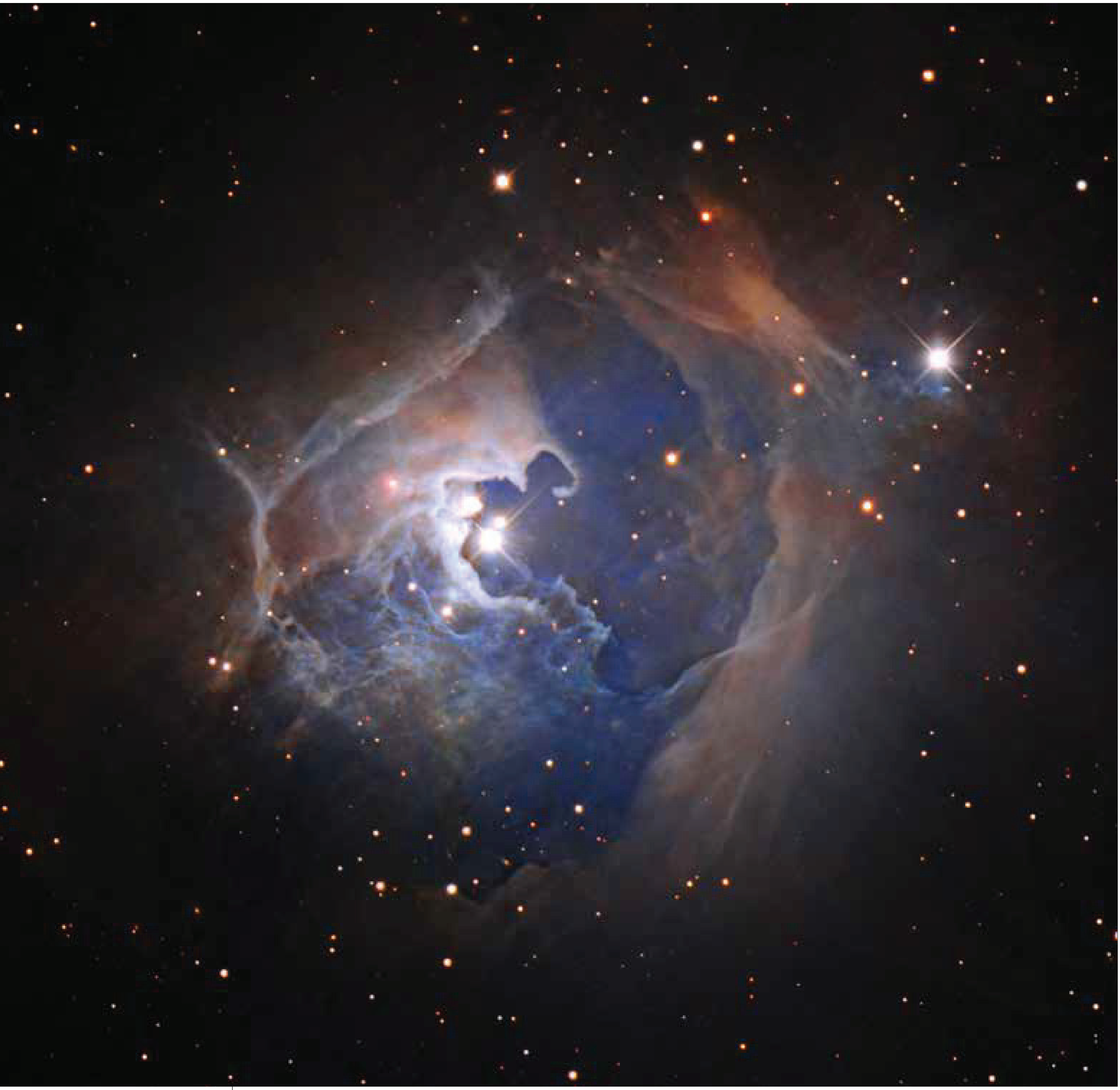
4. NISHIMURA'S APPROACH
Comet Nishimura (C/2023 P1), discovered Aug. 12, quickly sprouted a thin ion tail over the following weeks as it neared perihelion. This shot was taken the morning of Sept. 2 with an 8-inch scope and LRGB exposures of 75, 100, 100, and 100 seconds.
· *Gerald Rhemann*

5. BLOWING IN THE WIND
The wavy structures visible in Nishimura's ion tail, seen here the morning of Sept. 6, were evidence of its interactions with the Sun's wind of charged particles. The imager took this with an 11-inch scope and a one-shot color camera, stacking seven 30-second frames. **· *Allen Hwang***

6. SEE YOU, SPACE COWBOY ...
Before Nishimura rode off into the sunrise, it sported an extremely long tail of over 7°, captured here Sept. 9 from the Sierra de Enguera mountains outside of Valencia, Spain. Nishimura's next pass through the inner solar system won't be for another four centuries.
· *José J. Chambó*

7. CAUGHT IN THE RIVER
A pair of open clusters dot the swirling dust lanes of the Milky Way: the Ptolemy Cluster (M7; in the frame's lower third, just right of center) and the Butterfly Cluster (M6; above and to the right of M7, against the dark background). This scene consists of 22 one-minute exposures taken with a full-frame DSLR and a 135mm lens at f/2.8 and ISO 1600.
· *Panagiotis Andreou*

SEND YOUR IMAGES TO: readergallery@astronomy.com.
Please include the date and location of the image and complete photo data: telescope, camera, filters, and exposures.



REFLECTIONS ON AN INFANT STAR

Day in and day out, the Sun is a model of consistency. Like most other middle-aged stars, it changes little over the course of years, centuries, or even millennia. But not all stars behave so well. Old stars grow unstable near the end of their lives, swelling to humongous sizes and then slowly varying in brightness. Young stars, on the other hand, act erratically. HP Tauri is a classic example. This fledgling star, no more than 10 million years old, fluctuates between 15th and 17th magnitude. HP Tauri belongs to the triple-star system at the heart of the dusty reflection nebula that dominates this image. It lies 6° due north of Aldebaran and 560 light-years from Earth. KPNO/NOIRLAB/NSF/AURA/P. MASSEY

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SPECIAL
Pull-out section

Astronomy's 2024 Guide to the Night Sky

LUNAR PHASES

New	First Quarter	Full	Last Quarter
			Jan. 3
Jan. 11	Jan. 17	Jan. 25	Feb. 2
Feb. 9	Feb. 16	Feb. 24	March 3
March 10	March 17	March 25	April 1
April 8	April 15	April 23	May 1
May 7	May 15	May 23	May 30
June 6	June 14	June 21	June 28
July 5	July 13	July 21	July 27
Aug. 4	Aug. 12	Aug. 19	Aug. 26
Sept. 2	Sept. 11	Sept. 17	Sept. 24
Oct. 2	Oct. 10	Oct. 17	Oct. 24
Nov. 1	Nov. 9	Nov. 15	Nov. 22
Dec. 1	Dec. 8	Dec. 15	Dec. 22
Dec. 30			

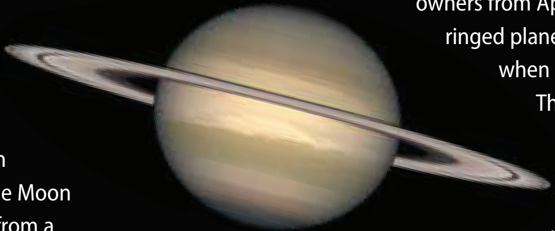
All dates are for the Eastern time zone. A Full Moon rises at sunset and remains visible all night; a New Moon crosses the sky with the Sun and can't be seen.

VENUS shines brilliantly before dawn from New Year's Day until March. It then disappears in the Sun's glow before returning to view at dusk in the latter half of July. The inner planet remains an evening fixture the rest of the year, glowing brighter and climbing higher each month. By late December, Venus gleams at magnitude –4.4 well above the southwestern horizon. NASA/JPL-CALTECH

MARS begins the year lost in the Sun's glare, but reappears before dawn in late January. The Red Planet grows more prominent as the year progresses — especially so in autumn and winter. By the end of the year, it shines at magnitude –1.2 and shows a 14"-diameter disk when viewed through a telescope. It will peak in mid-January 2025. NASA/ESA/J. BELL (CORNELL U.)/M. WOLFF (SSI)

JUPITER always looks dramatic through a telescope. Even small instruments show the planet's four big moons and resolve its dynamic atmosphere into a series of bright zones and darker belts. Jupiter appears best around opposition in early December, when it shines brightest (magnitude –2.8) and looms largest (48" across), though it's a fine sight all year except in the weeks around solar conjunction in May.

NASA/ESA/A. SIMON (GSFC)/M.H. WONG (UC, BERKELEY)/THE OPAL TEAM



SATURN provides a thrill for telescope owners from April through December. The ringed planet peaks in early September, when it glows at magnitude 0.5. The ring system then spans 43" and tilts 4° to our line of sight. The rings will appear edge-on in 2025 for the first time in 16 years. NASA/ESA/

THE HUBBLE HERITAGE TEAM (STSCI/AURA)

THE MOON is Earth's nearest neighbor and the only celestial object humans have visited. Because of its changing position relative to the Sun and Earth, the Moon appears to go through phases, from a slender crescent to Full Moon and back. The best times to observe our satellite through a telescope come a few days on either side of its two Quarter phases. For the best detail, look along the terminator — the line separating the sunlit and dark parts. NASA/GSFC/ARIZONA STATE UNIVERSITY

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WINTER

The sky

Winter boasts the brightest stars of any season. Orion the Hunter dominates the evening sky this time of year. Its seven most prominent stars form a distinctive hourglass pattern. The blue star marking Orion's left foot is Rigel, and the ruddy gem at his right shoulder is Betelgeuse. The three stars of the Hunter's Belt point down to Sirius, the brightest star in the night sky, and up to Aldebaran, the eye of Taurus the Bull. To Orion's upper left lies the constellation Gemini.

Deep-sky highlights

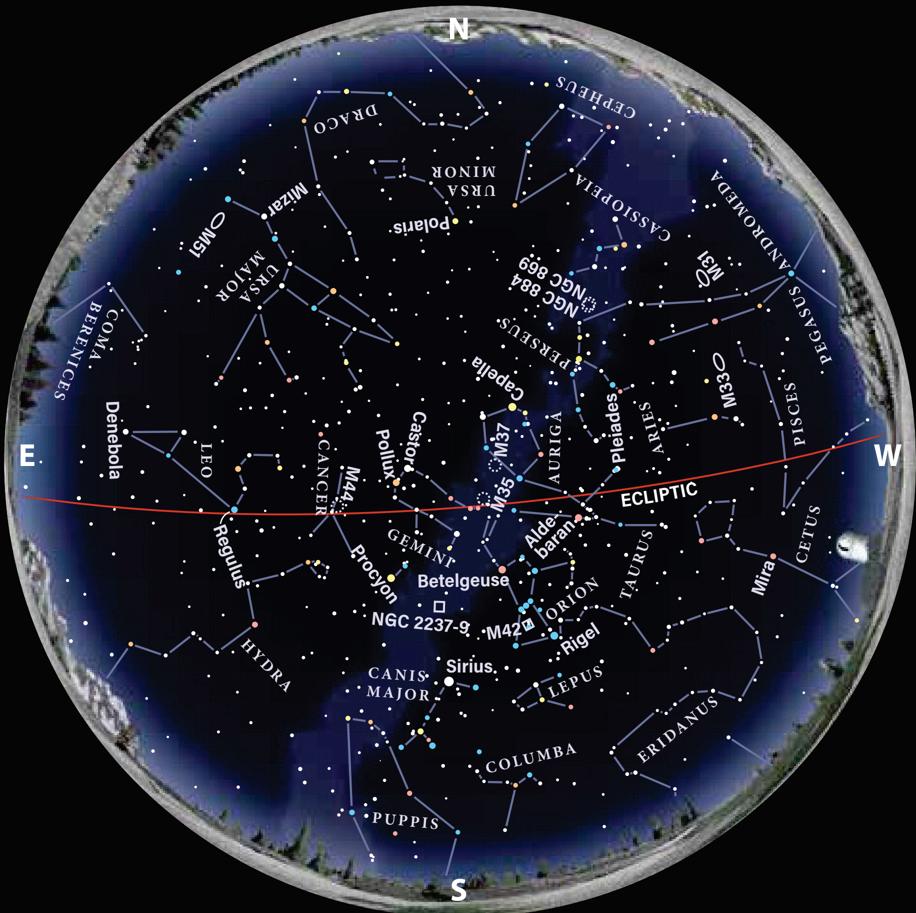
The Pleiades (M45) is the brightest star cluster in the sky. It looks like a small dipper, but it is not the Little Dipper.

The Orion Nebula (M42), a region of active star formation, is a showpiece through telescopes of all sizes.

The Rosette Nebula (NGC 2237–9/46), located 10° east of Betelgeuse, presents an impressive cluster of stars and a nebula.

M35 in Gemini the Twins is a beautiful open cluster best viewed with a telescope.

Castor (Alpha [α] Geminorum) is easy to split into two components with a small telescope, but the system actually consists of six stars.



SPRING

The sky

The Big Dipper, the most conspicuous part of the constellation Ursa Major the Great Bear, now rides high in the sky. Poke a hole in the bottom of the dipper's bowl, and the water would fall on the back of Leo the Lion. The two stars at the end of the bowl, called the Pointer Stars, lead you directly to Polaris, the North Star: From the bowl's top, simply go five times the distance between the Pointers. Spring is the best time of year to observe a multitude of galaxies. Many of these far-flung island universes, containing hundreds of billions of stars, congregate in northern Virgo and Coma Berenices.

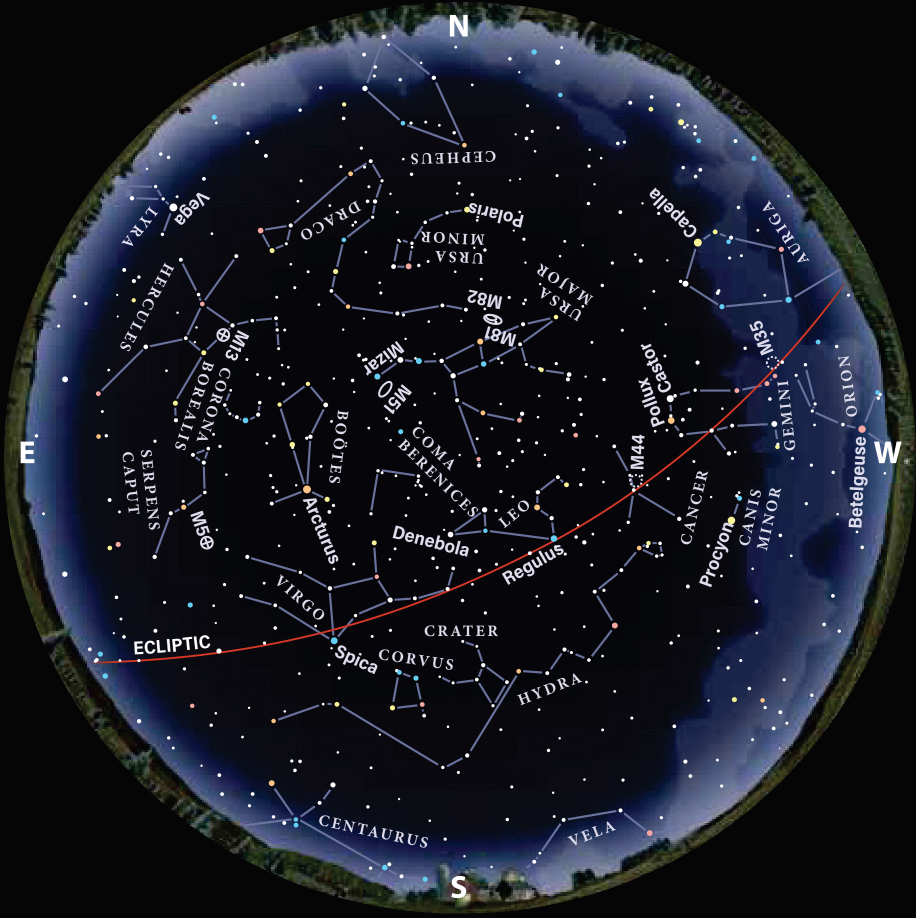
Deep-sky highlights

The Beehive Cluster (M44) was used to forecast weather in antiquity. It is a naked-eye object under a clear, dark sky, but it disappears under less optimal conditions.

M5, a conspicuous globular cluster, lies between the figures of Virgo the Maiden and Serpens Caput the Serpent's Head.

The Whirlpool Galaxy (M51) is a vast spiral about 30 million light-years away.

M81 and **M82** in Ursa Major form a pair of galaxies that you can spot through a telescope at low power.



STAR MAPS BY *ASTRONOMY*: ROEN KELLY

Jan. 4
Quadrantid meteor shower peaks

Jan. 12
Mercury is at greatest western elongation

March 3
Asteroid Juno is at opposition

March 24
Mercury is at greatest eastern elongation

April 8
Total solar eclipse

April 22
Lyrid meteor shower peaks

May 5
Eta Aquariid meteor shower peaks

May 19
Asteroid Pallas is at opposition

July 5
Dwarf planet Ceres is at opposition

July 22
Mercury is at greatest eastern elongation

July 23
Pluto is at opposition

Aug. 12
Perseid meteor shower peaks

Sept. 4
Mercury is at greatest western elongation

Sept. 8
Saturn is at opposition

Sept. 17
Partial lunar eclipse

Sept. 20
Neptune is at opposition

Oct. 2
Annular solar eclipse

Oct. 21
Orionid meteor shower peaks

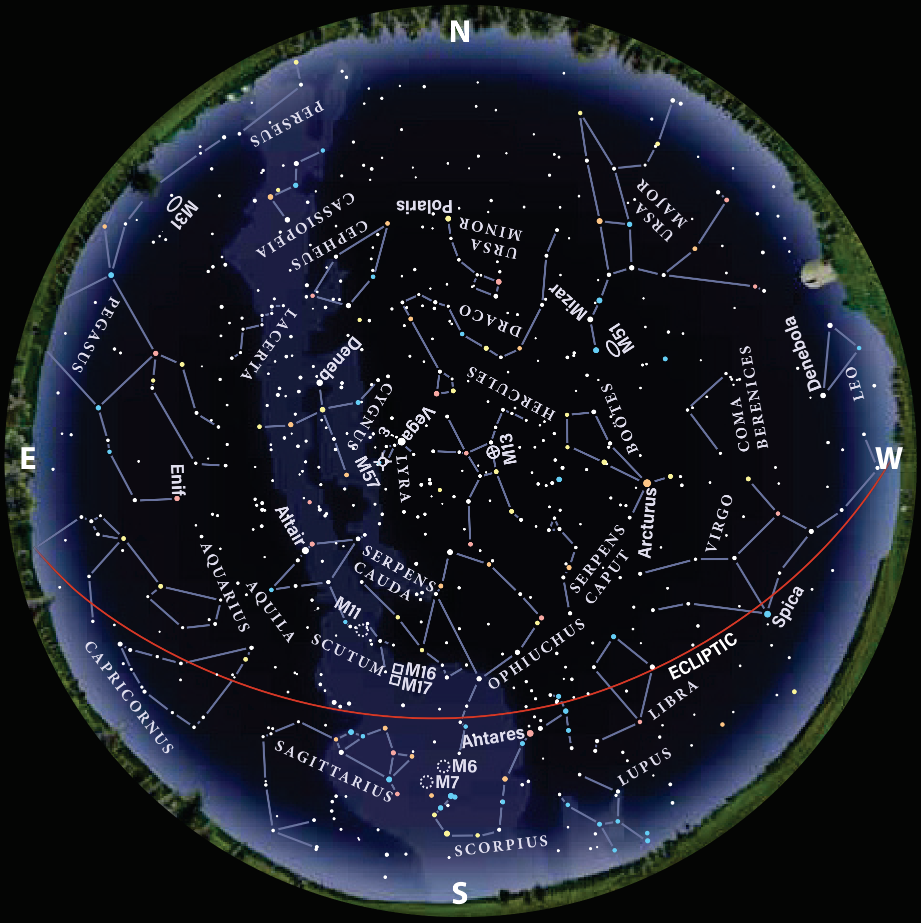
Nov. 16
Uranus is at opposition

Dec. 7
Jupiter is at opposition

Dec. 13
Geminid meteor shower peaks

Dec. 24
Mercury is at greatest western elongation

SUMMER



The sky

High in the sky, the three bright stars known as the Summer Triangle are easy to spot. These luminaries — Vega in Lyra, Deneb in Cygnus, and Altair in Aquila — lie near the starry path of the Milky Way. Following the Milky Way south from Aquila, you'll find the center of our galaxy in the constellation Sagittarius the Archer. Here lie countless star clusters and glowing gas clouds. Just west of Sagittarius is Scorpius the Scorpion, which contains the red supergiant star Antares as well as M6 and M7, two brilliant clusters that look marvelous at low power.

Deep-sky highlights

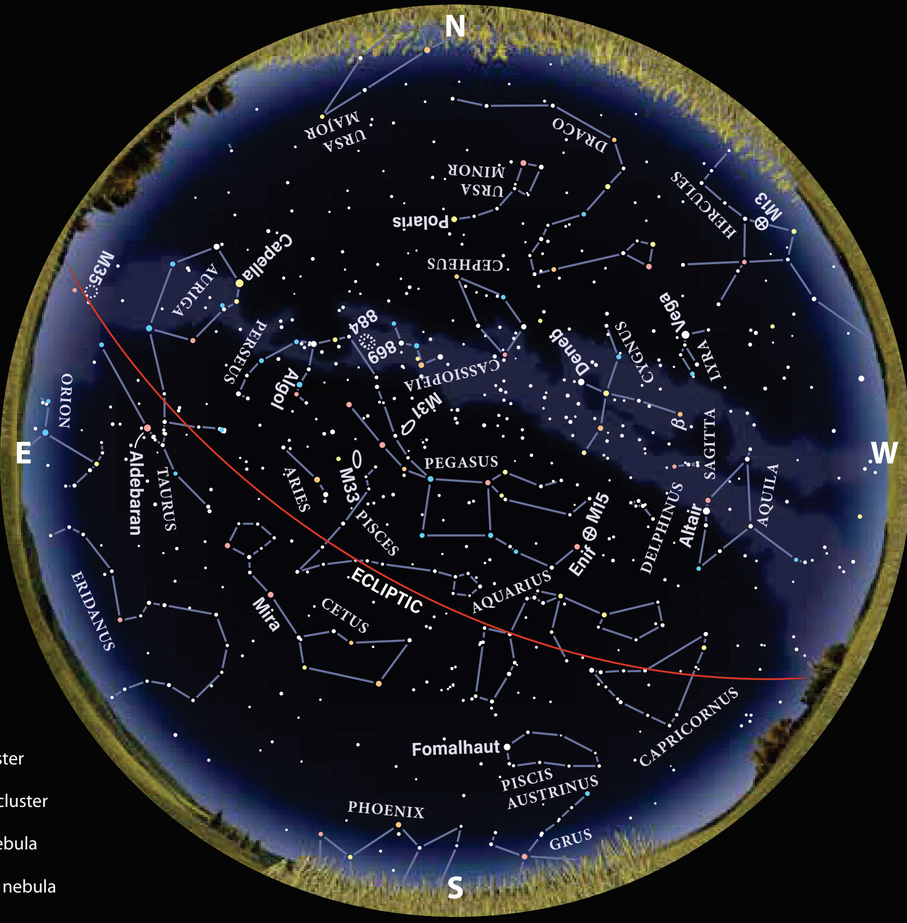
The Hercules Cluster (M13) contains nearly a million stars and is the finest globular cluster in the northern sky.

The Ring Nebula (M57) looks like a puff of smoke through a medium-sized telescope.

The Omega Nebula (M17) looks like the Greek letter of its name (Ω) through a telescope at low power. This object also is called the Swan Nebula.

The Wild Duck Cluster (M11) is a glorious open star cluster. On a moonless night, a small scope will show you some 50 stars.

AUTUMN



The sky

The Big Dipper swings low this season, and from parts of the southern U.S., it even sets. With the coming of cooler nights, Pegasus the Winged Horse rides high in the sky as the rich summer Milky Way descends in the west. Fomalhaut, a solitary bright star, lies low in the south. The magnificent Andromeda Galaxy reaches its peak nearly overhead on autumn evenings, as does the famous Double Cluster. Both of these objects appear as fuzzy patches to the naked eye under a dark sky.

Deep-sky highlights

The Andromeda Galaxy (M31) is the brightest naked-eye object outside our galaxy visible in the northern sky.

The Double Cluster (NGC 869 and NGC 884) in Perseus consists of twin open star clusters. It's a great sight through binoculars.

M15 in Pegasus is a globular cluster containing hundreds of thousands of stars, many of which can be glimpsed through a medium-sized telescope.

Albireo (Beta [β] Cygni), the most beautiful double star in the sky, is made up of suns colored sapphire and gold.

◌ Open cluster
⊕ Globular cluster
☐ Diffuse nebula
⌖ Planetary nebula
⬭ Galaxy

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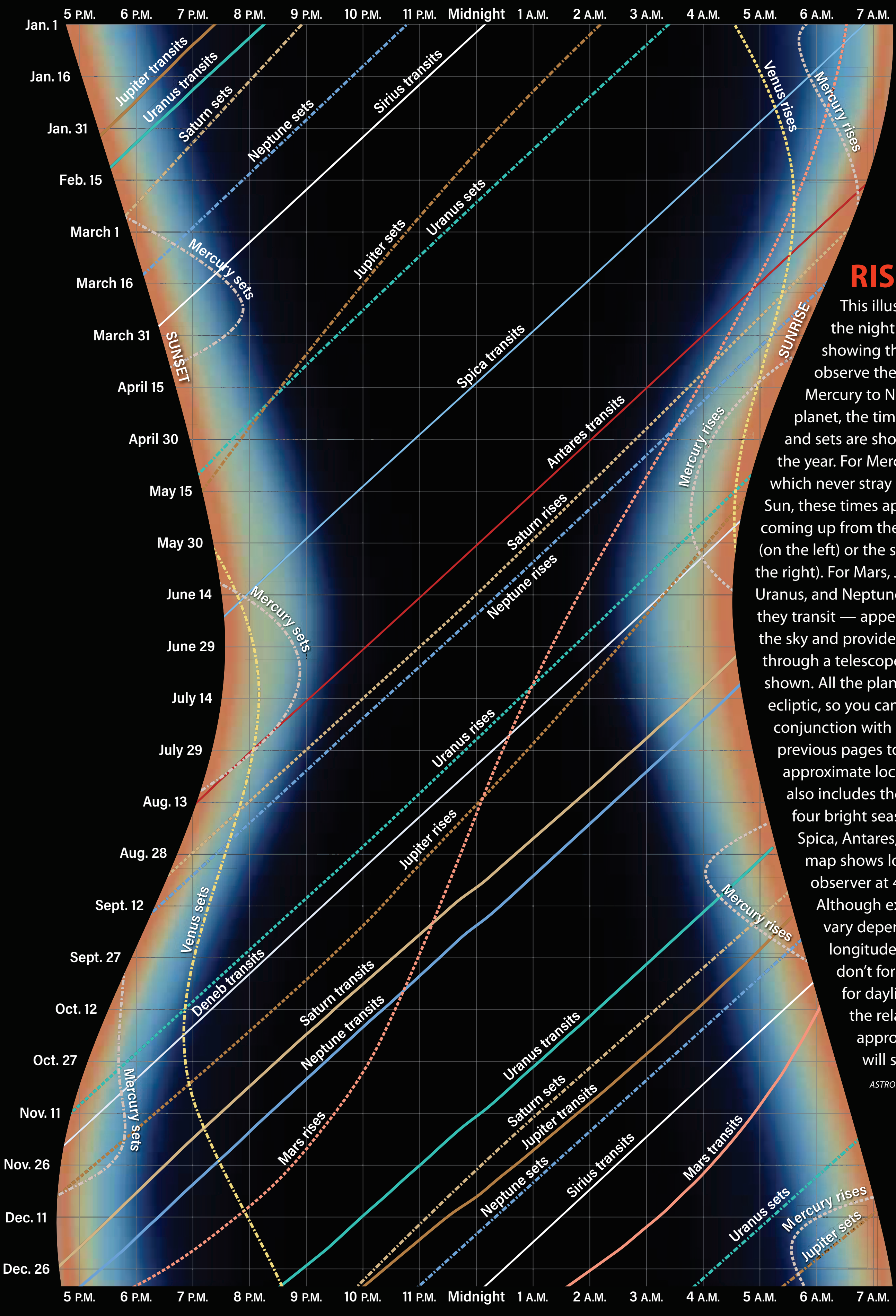

RISE & SET

This illustration presents the night sky for 2024, showing the best times to observe the planets from Mercury to Neptune. For each planet, the times when it rises and sets are shown throughout the year. For Mercury and Venus, which never stray too far from the Sun, these times appear as loops coming up from the sunset horizon (on the left) or the sunrise horizon (on the right). For Mars, Jupiter, Saturn, Uranus, and Neptune, the times when they transit — appear highest in the sky and provide the best view through a telescope — also are shown. All the planets lie near the ecliptic, so you can use this chart in conjunction with the maps on the previous pages to find a planet's approximate location. The chart also includes the transit times of four bright seasonal stars: Sirius, Spica, Antares, and Deneb. This map shows local times for an observer at 40° north latitude. Although exact times will vary depending on your longitude and latitude (and don't forget to add an hour for daylight saving time), the relative times and approximate positions will stay the same.

ASTRONOMY: ROEN KELLY